Use of NASA LDAS Products to Improve Flood and Drought Risk Analysis and Forecasting in the Columbia River Basin

UMBC/NASA Investigator:
Kristi R. Arsenault

Reclamation Investigators:
Steven Hunter, Edmond Holroyd III, and Steffen Meyer

GMU: Paul R. Houser

NASA SENH Program Review

May 3-5, 2005

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Introduction

- Accurate and timely hydrometeorological information is essential for reservoir operations and river basin management conducted at the Bureau of Reclamation (Reclamation) facilities.
- Consequently, river basin managers must have timely data from remote areas that are often inaccessible in winter, and have a means of quickly analyzing the impacts of precipitation and snowmelt on streamflow for routine river system management, and emergency responses to extreme events.
- Therefore, a collaboration between the U.S. Bureau of Reclamation, NASA, and university partners was established to address these issues

Objectives

- The main objective of the project is to demonstrate the value added by information from satellite, radar, and the Land Surface Data Assimilation System (LDAS) toward the improvement of flood and drought risk analyses and forecasts.

- These products will be tested by water resource managers in the Yakima River Basin and further developed and adapted by Reclamation researchers at the main Denver office

Objectives

- Results from the LDAS land surface models (LSMs) and hydrologic runoff models will be integrated into the river basin decision support systems that the Reclamation's managers routinely use to manage the complex operation of the river system.
- The applications work focuses on the "leave behind" concept where an improved hydrologic operation and forecasting system is being developed through major collaborative efforts between NASA and Reclamation.
- The improved system will be implemented into water resource management operations and flood and drought forecasting after successful demonstration of this project.

Reclamation's Functions

Fifth largest electric utility - West
Nation's largest water supplier,
Administering 348 reservoirs
Total Storage: 245 MAF

Provides 1 out of 5 Western farmers (140,000) with irrigation water for 10 million farmland acres that produce 60% of the nation's vegetables and 25% of its fruits and nuts

Operates 58 hydroelectric power plants averaging 42 Billion kilowatt-hours annually

Delivers 10 trillion gallons of water to more than 31 million people each year

Manages in partnership 308 recreation sites visited by 90 million people a year

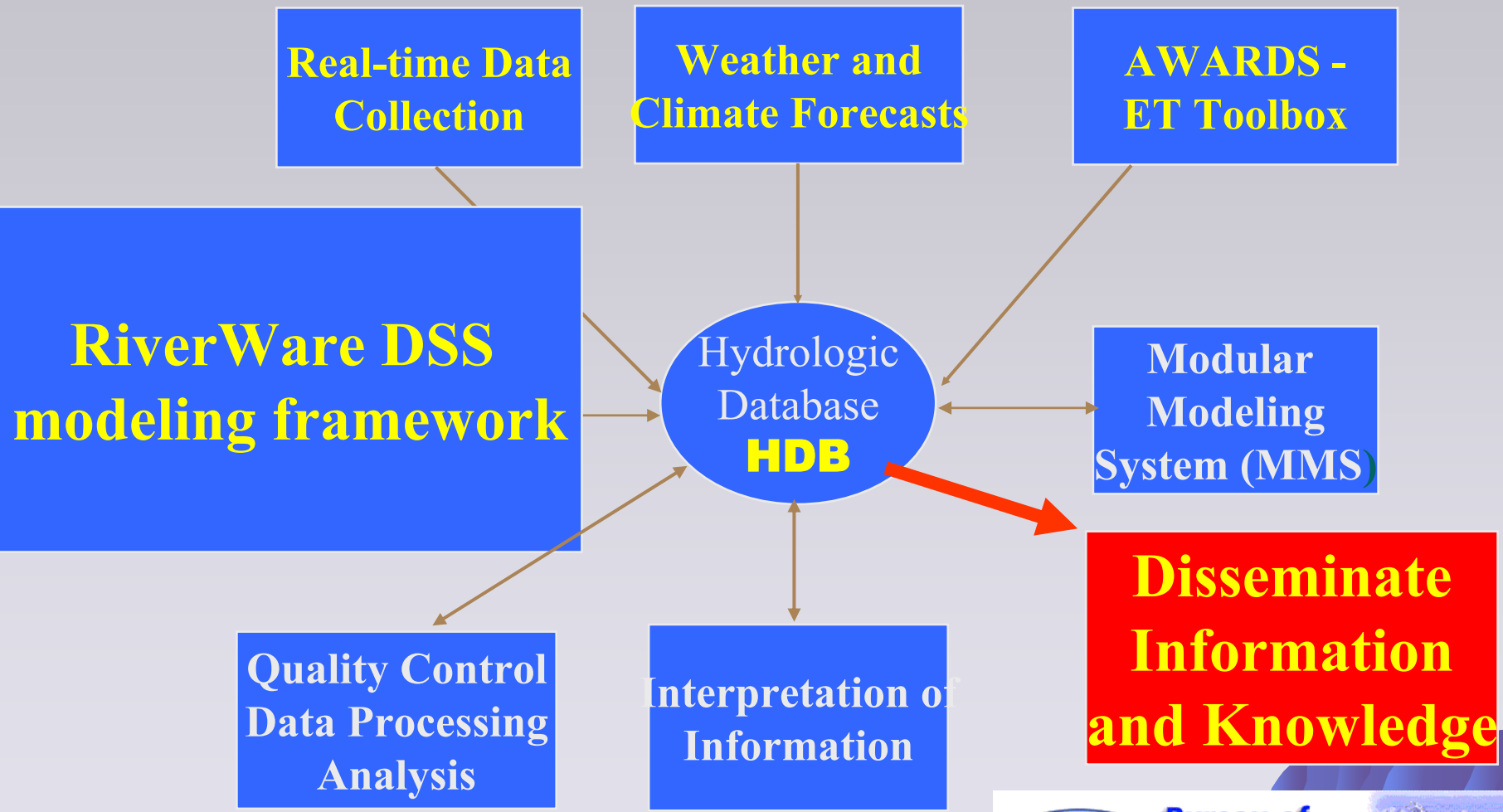
Reclamation's Goals

- **Improve the management of scarce water supplies by enhancing the efficiency and effectiveness of river system management**
  - **More accurate water supply forecasts – Volume and timing**
    - **Snow Water Equivalent - 80% of the supply**
    - **Summer Monsoon Precipitation 20-40% in the SW**

Reclamation's Goal

- **More accurate scheduling of water delivery**
  - **Irrigation demands – Crops and groundwater losses**
  - **Riparian consumptive uses / losses**
  - **Open-water evaporation**
  - **River losses – bank storage, wet sand evaporation.**
  - **Groundwater transports**
  - **Return flows**

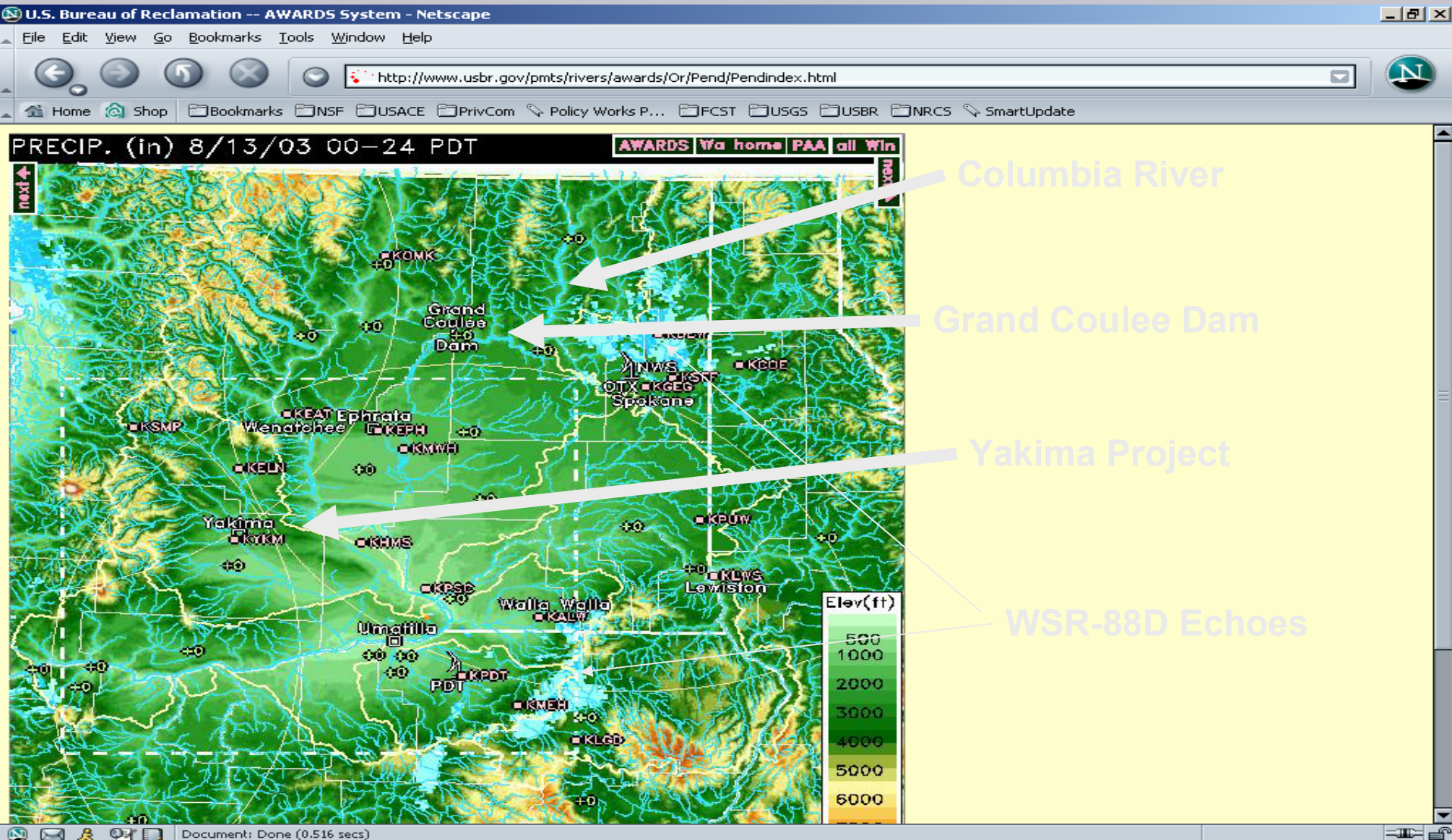
Decision Support System Tool Box for Water Resource Managers



Bureau of Reclamation
Managing Water In The American West

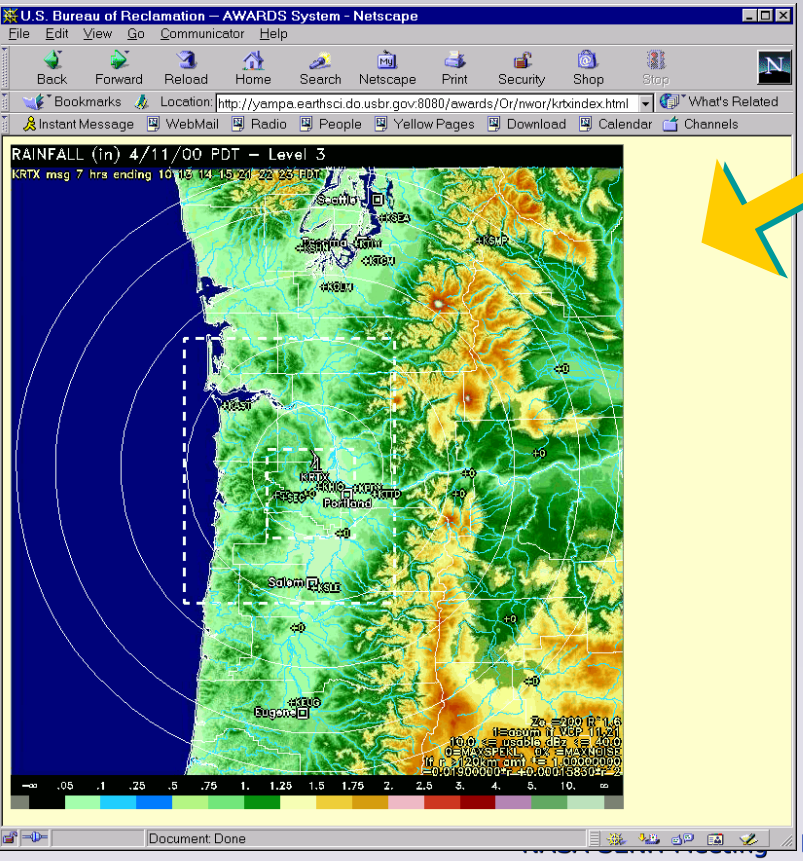
AWARDS-ET Toolbox

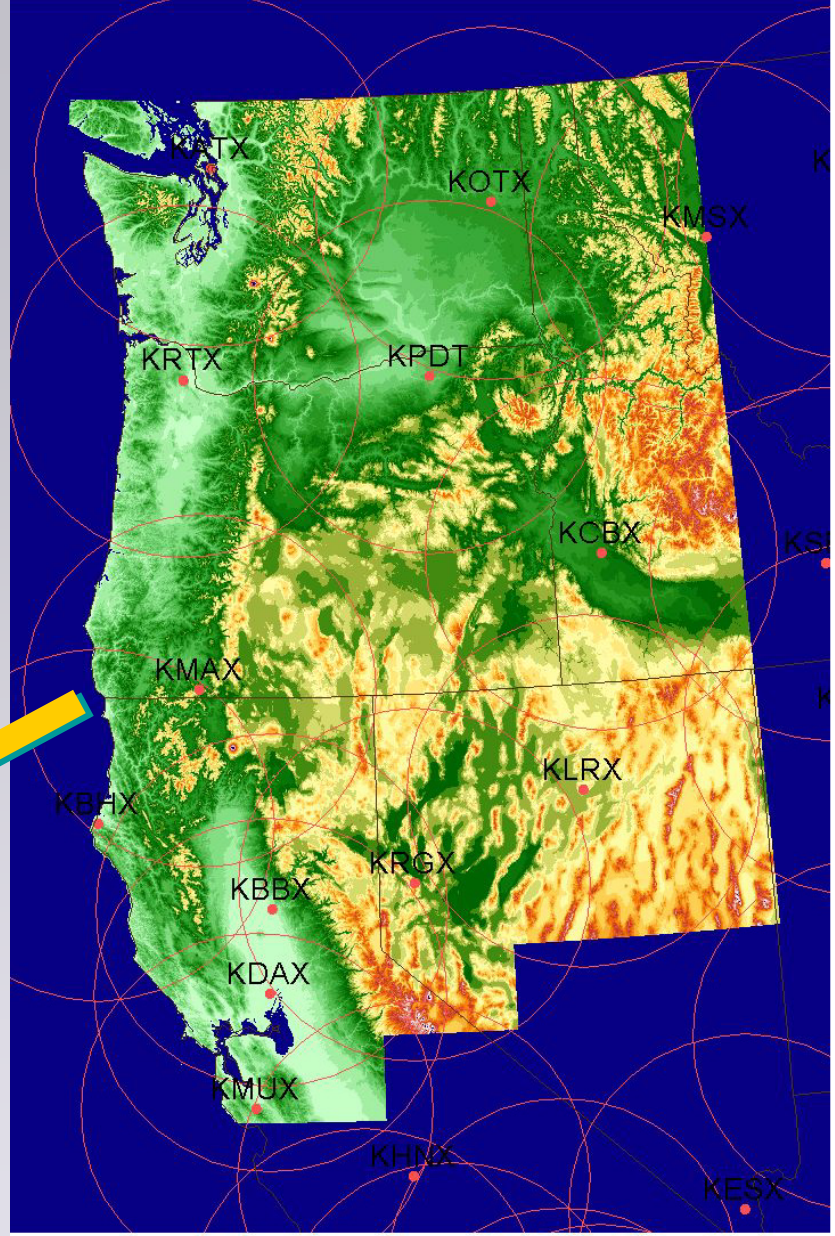
August 13, 2003 example

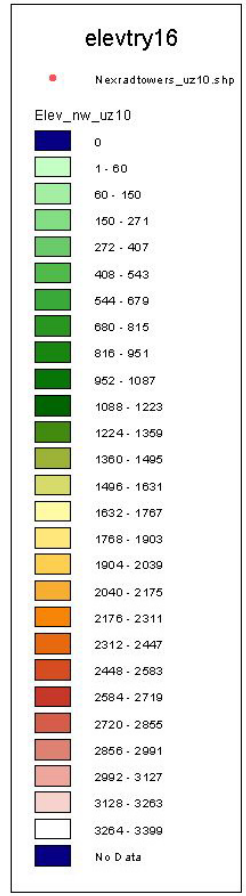


Reclamation PAA

- GIS technology uses Digital Elevation Model (DEM) products used to create terrain backdrop
- Display must be accurate, small for rapid web delivery, readable, and accept NEXRAD/HRAP real-time update automatically


U.S. Bureau of Reclamation – AWARDS System - Netscape
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://yampa.earthsci.do.usbr.gov:8080/awards/Or/nwor/krtxindex.html What's Related
Instant Message WebMail Radio People Yellow Pages Download Calendar Channels
RAINFALL (in) 4/11/00 PDT – Level 3
KRTX msg 7 hrs ending 10 13 14 15 21 22 23 PDT
Seattle
Portland
Salem
Eugene
Document: Done





Pacific Northwest
NEXRAD Radar Coverage

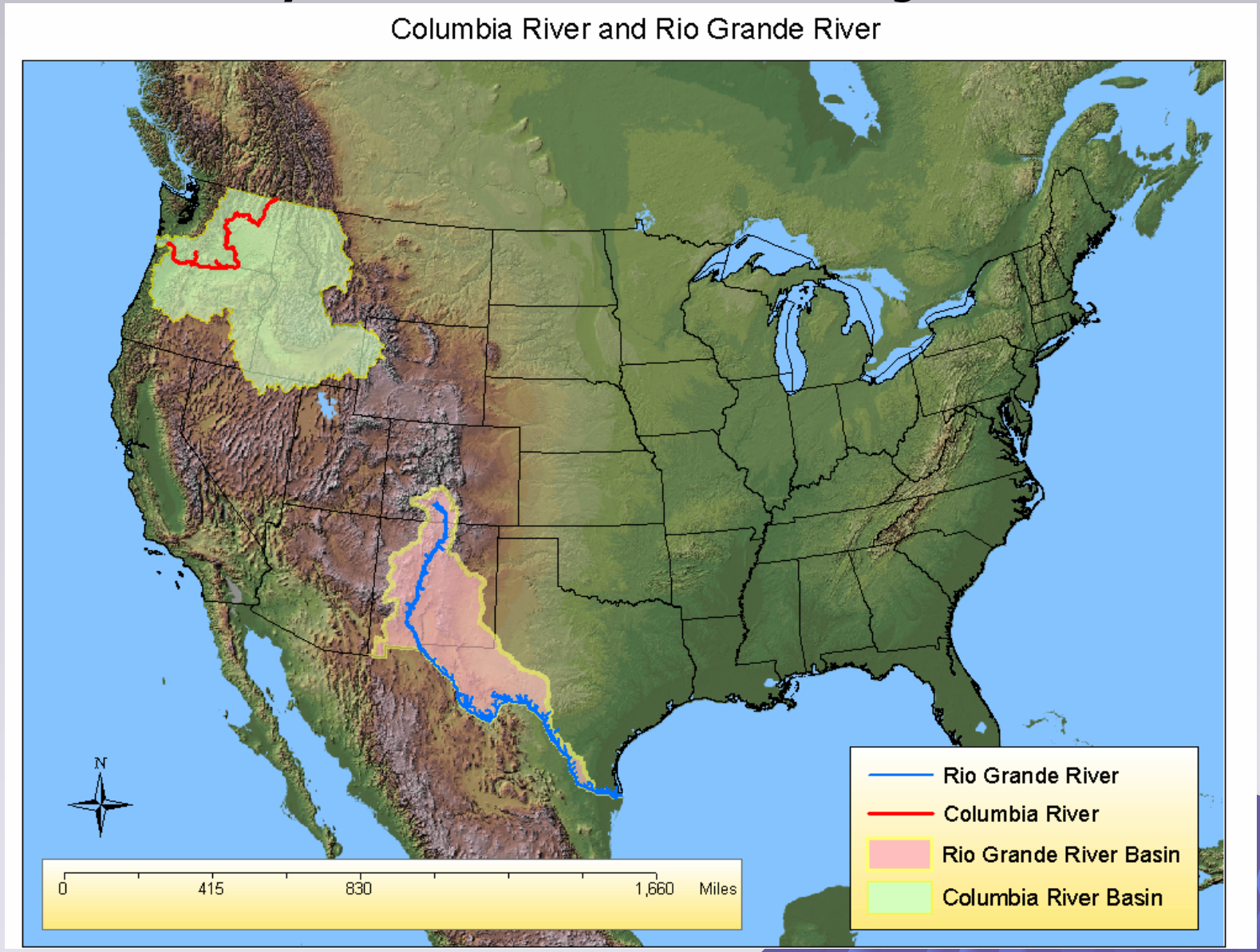
N

US Bureau of Reclamatio
River Systems and Meteorology Grou
Denver Technical Service Cente

NASA/NOAA LDAS Expectations

- **Remote Sensing, GIS, and Land Surface Modeling** advances will provide significant improvements in short to medium range (1 to 14 day) forecasting of water supplies and demands
- **Four Dimensional Data Assimilation** techniques are enabling more effective use of remote sensing systems, mesonet observations, and numerical models

Currently: Two Joint Project Areas



Overview

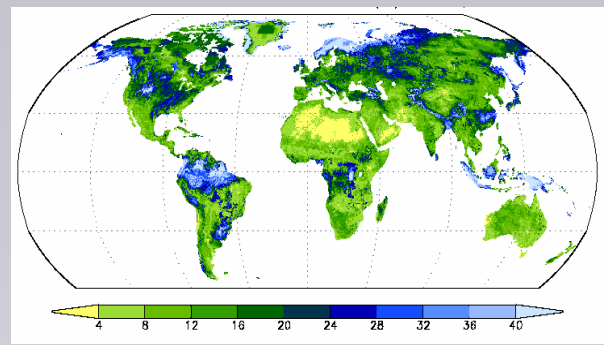
- Two main projects:
  - **Columbia River**
    - Streamflow forecasts
    - Assimilated MODIS snow cover and albedo datasets in land surface models
    - 1996 Retrospective study using specialized LDAS case and forcing (e.g., NCEP Regional Reanalysis)
  - **Rio Grande River**
    - Soil moisture and ET studies for irrigated and riparian areas
    - Evaluate soil and ET components related to more drought type conditions
    - Test and implement LDAS in ET Toolbox

Land Data Assimilation System (LDAS)

GOAL: Produce optimal output fields of land surface states and fluxes.

APPROACH: Parameterize, force, and constrain multiple, sophisticated land surface models with data from advanced ground and space-based observing systems.

Assimilation



Root zone soil water content [%]

FORCING DATA

- Precipitation
- Temperature
- Radiation
- Other variables

PARAMETERS

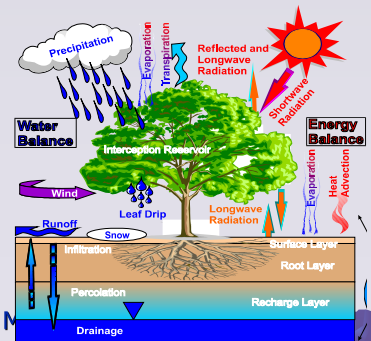
- Vegetation Types
- Soil Classes
- Elevation
- Other data

LDAS

North American LDAS

Global LDAS

Land Surface Models

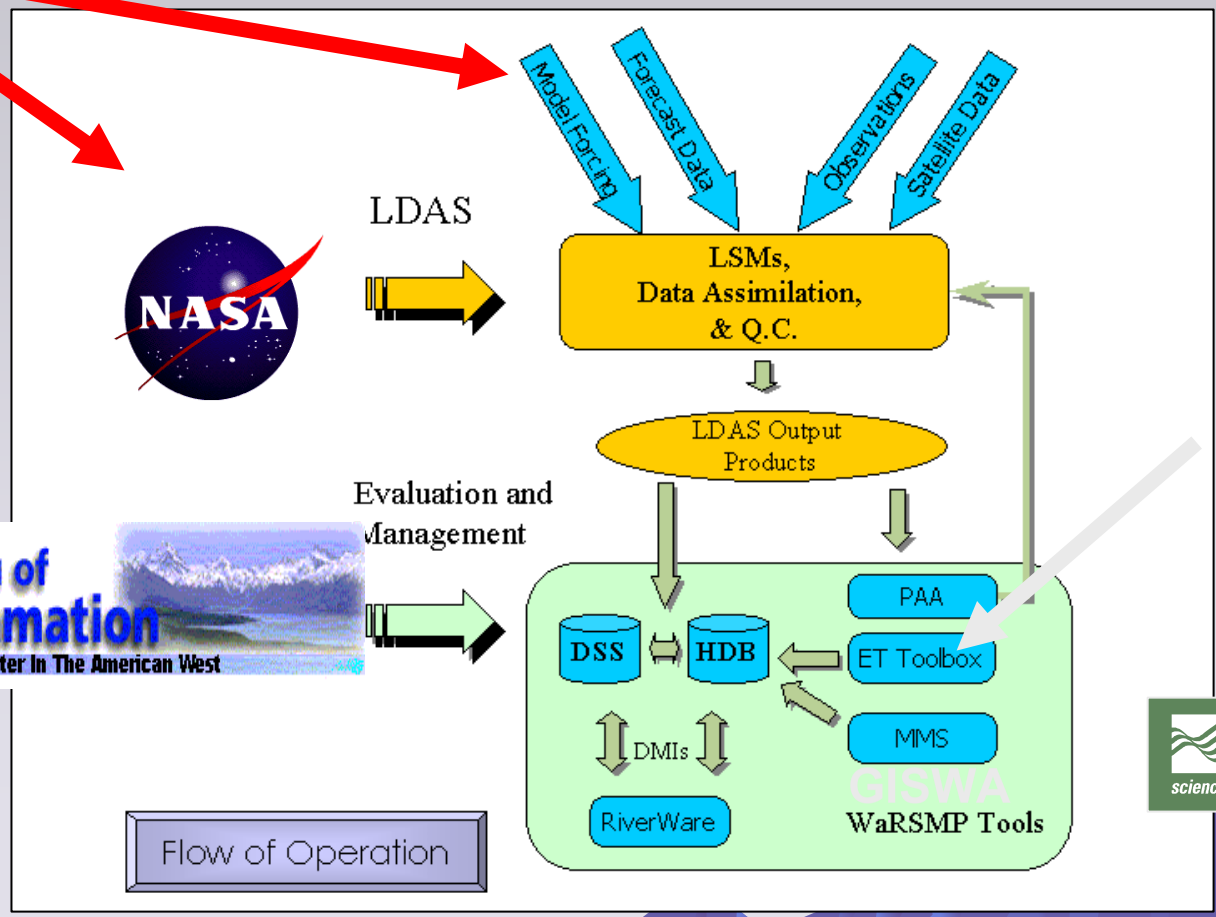


Output

- Soil Moisture
- Evapotranspiration
- Energy fluxes
- River runoff
- Snowpack characteristics

Flow of Operations

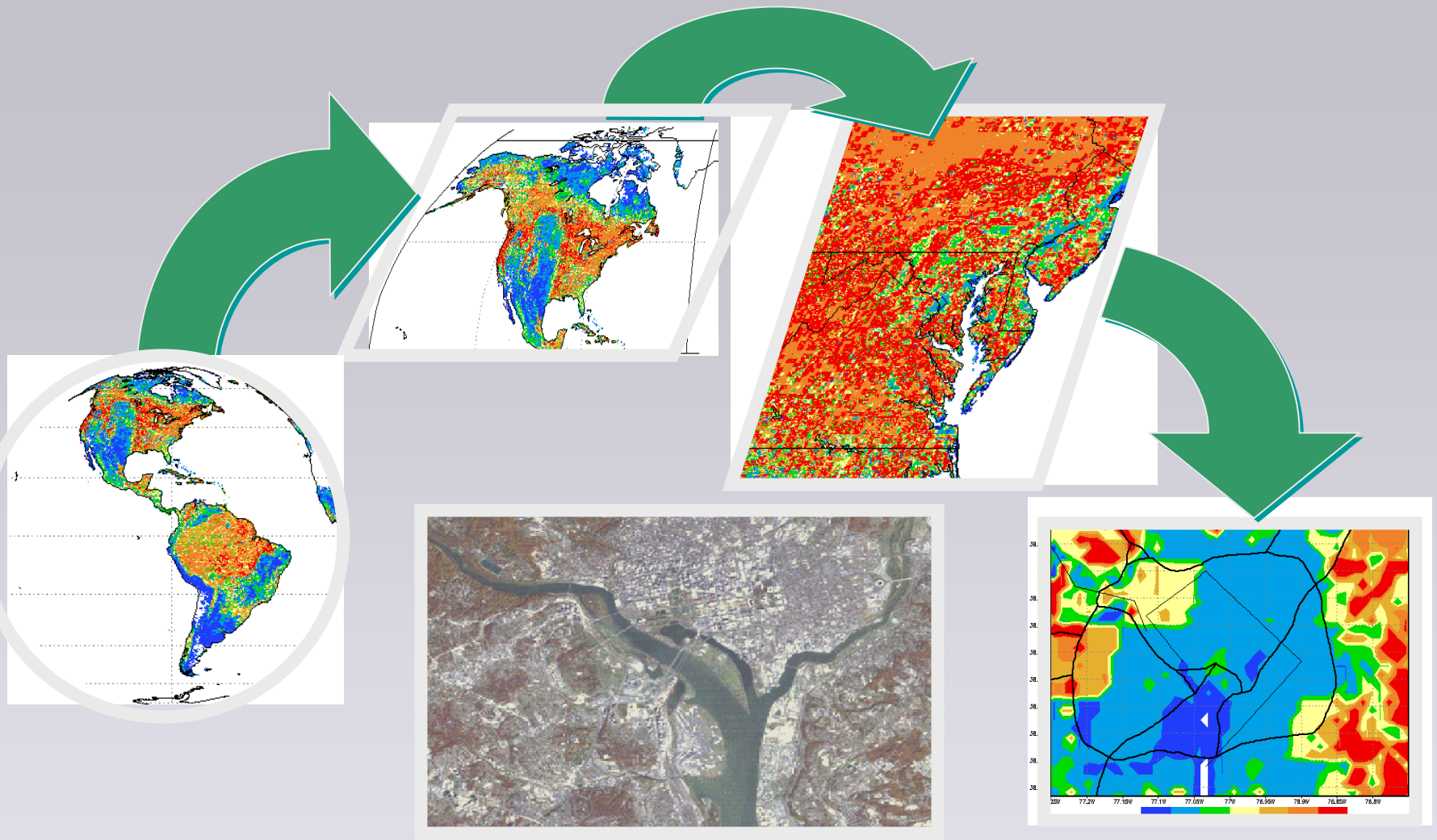
NWS NCEP Model Products



ET Toolbox

Columbia,
Colorado,
Rio Grande
Truckee Basins….

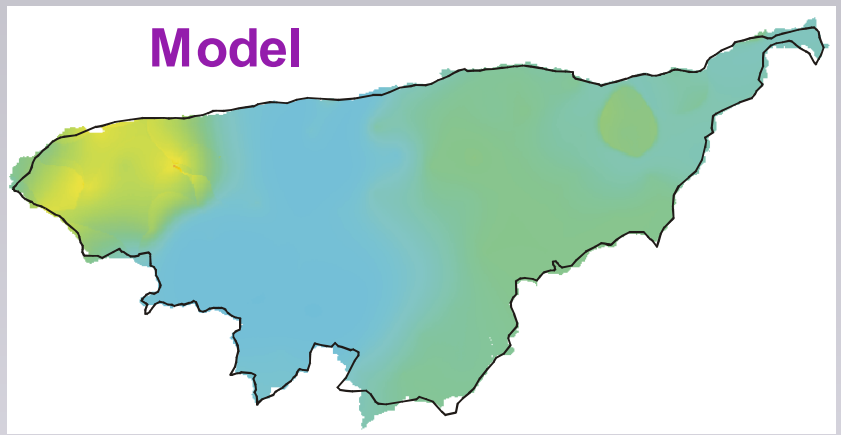
LAND INFORMATION SYSTEM

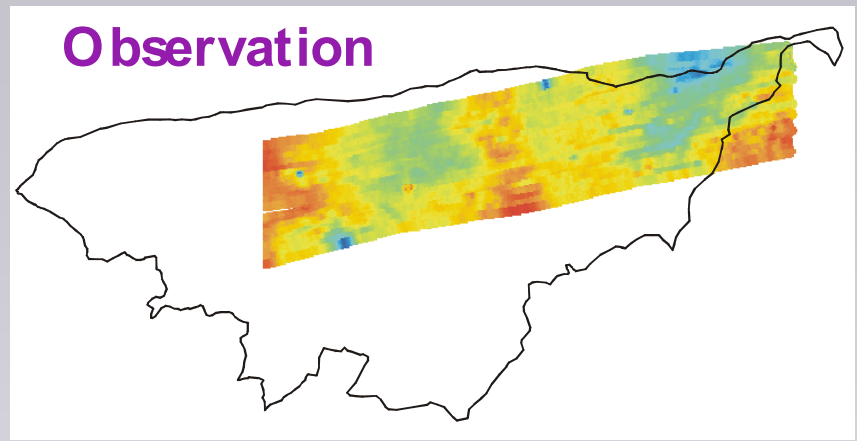


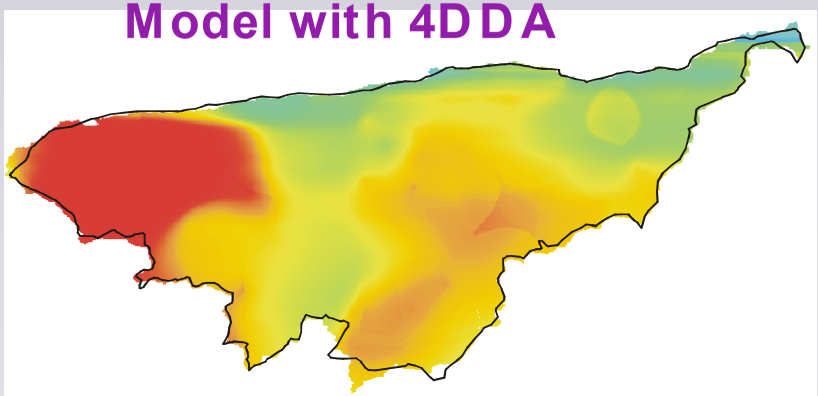
Resolution	1/4 deg	5 km	1 km
Land Grid Points	2.43E+05	5.73E+06	1.44E+08
Disk Space/Day (Gb)	1	28	694
Memory (Gb)	3	62	1561

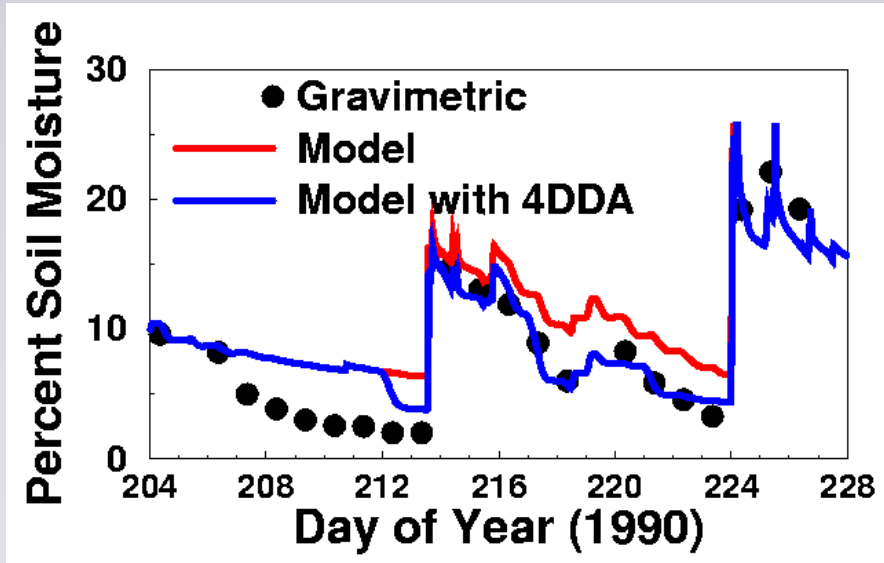
Land Data Assimilation

Temperature, snow, soil moisture, etc., are integrated into a hydrologic model to improve prediction.









Walnut Gulch, AZ (MONSOON 1990)

Diagram of Use of LDAS/LIS for Meeting Reclamation Needs: Columbia River Basin

New 12-km Eta Resolution for NLDAS:

- NLDAS Project is converting to the new 12-km Eta model resolution
- to be used for real-time, retrospective, and forecasting runs
- This domain will provide a larger window for regions of interest

1-km MODIS and Datasets Used for Designated Regions:

- All relevant 1-km MODIS datasets (snow cover, vegetation type, albedo, leaf area index, etc.)
- Evaluation in two major LSMs: Noah (2.7.1) and CLM2
- Main focus: Assimilation techniques will be evaluated for snow along with most optimal snow model

Streamflow Modeling and Foreacasts:

- Implement runoff routing model in LDAS/LIS and test with MMS

LDAS Background

- The NLDAS project seeks to provide accurate, near-real-time and retrospective land surface states over North America
- Quality of land surface model (LSM) output is closely tied to the quality of the meteorological forcing data used to drive the model
- LSMs include: Mosaic, NOAH, VIC, Sacramento and CLM
- Model-based data are subject to model error, so observations are used when possible:

Radiation

- GOES-UMD downward shortwave, PAR, and skin temperature

Precipitation

- Stage II hourly Doppler radar/RFC gauge data
- CPC daily gauge data; and CPC reprocessed daily gauge data

LDAS/LIS Project Specifics

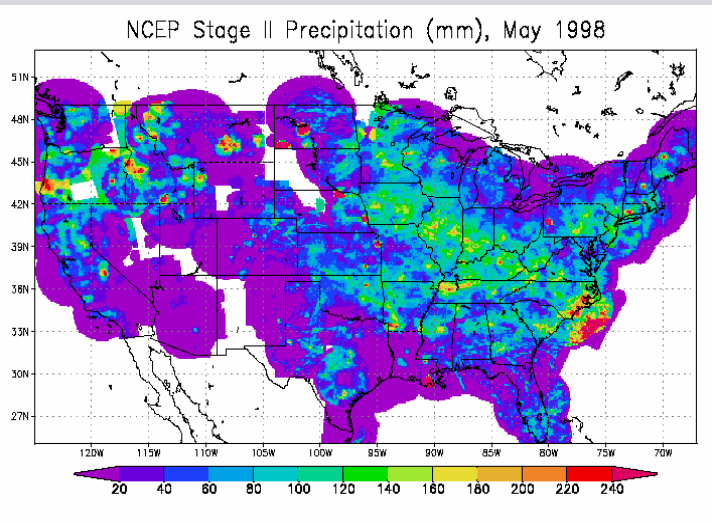
- *Spatial Resolutions*: **12** km (NLDAS) and **1** km (LIS)
- *Temporal Resolution*: ~ 15 minute time steps,
  1-hourly output fields
- *Land Surface Models*: Mosaic, CLM2, Noah, VIC-3L
- *Elevation*: GTOPO30 DEM, ~ 1 km
- *Vegetation Classification*:
- University of Maryland, 1 km,
  - AVHRR and MODIS vegetation class maps
- *Soils Definition*:
  - 1km Penn State STATSGO and 5 minute ARS

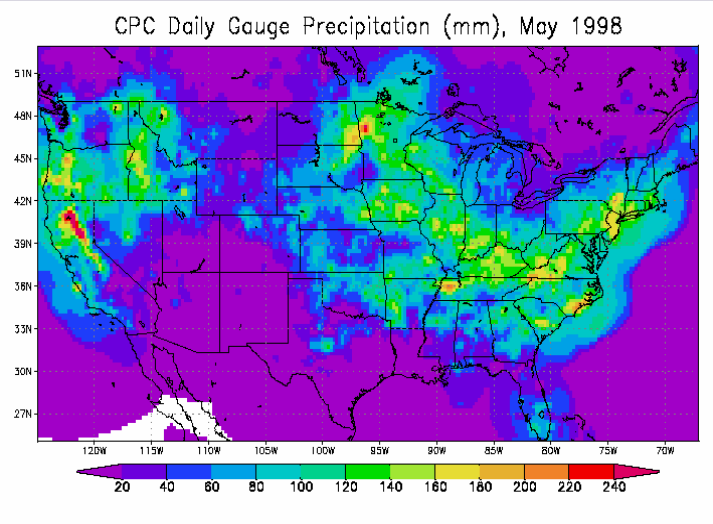
Forcing File Contents

Nine primary fields used by LDAS LSMs:

Model Based	Observation Based
2 Meter temperature	Downward shortwave radiation
2 Meter specific humidity	Doppler/gauge/model based precipitation
Surface Pressure	
U wind component	
V wind component	
Downward longwave radiation	
Convective Precipitation	

Observed Precipitation





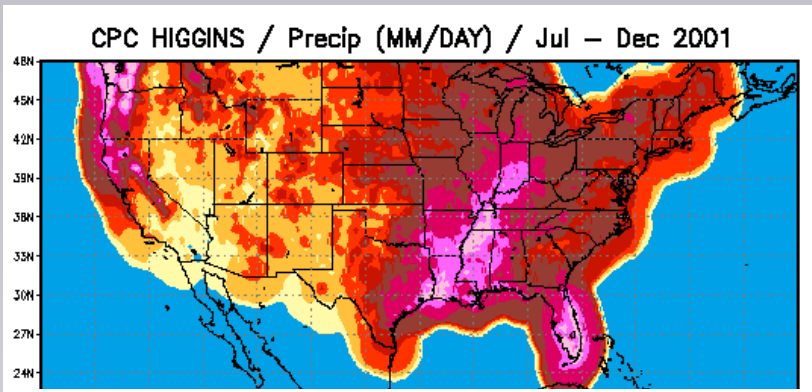
Make use of ETA, Stage II and CPC data to form best available product—a temporally disaggregated hourly CPC value

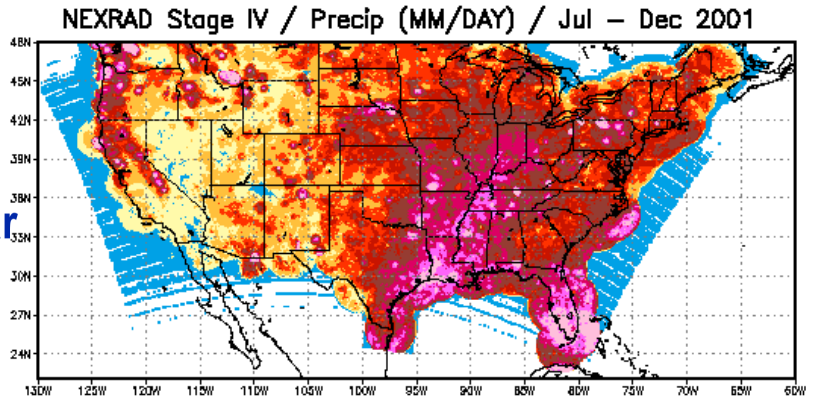
Precipitation Evaluation (Jul-Dec 2001)

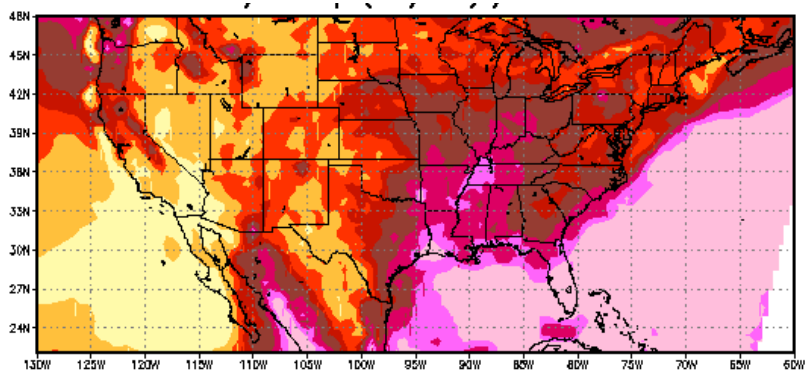
CPC 0.25° 24hr Gauge N. Am.

NCEP 4km 1hr Gage/Radar N. Am.

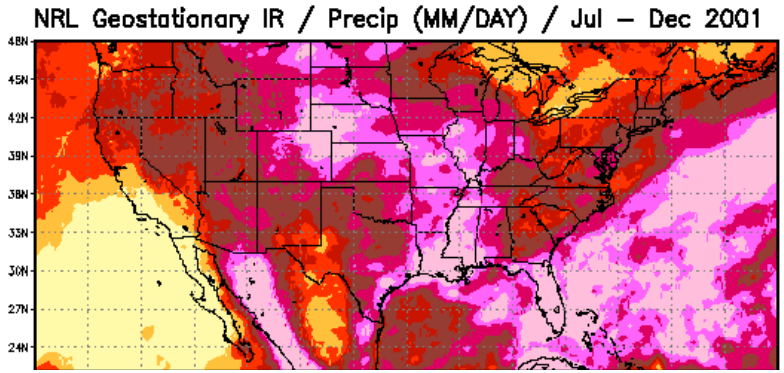
NCEP 40km 3hr NWP-N.Am.

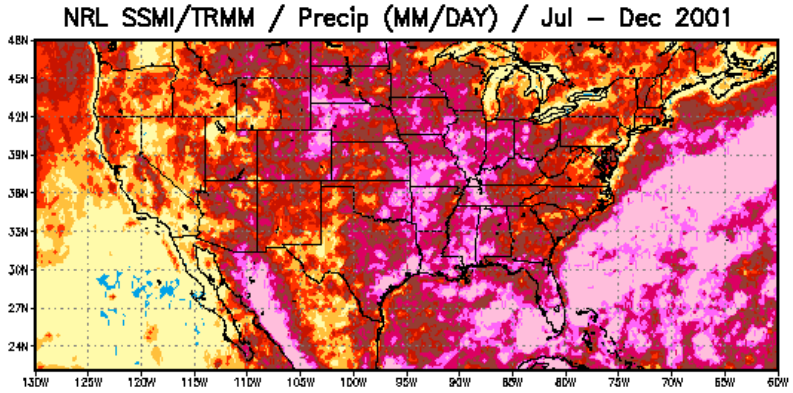






NRL 0.25° 6hr IR-Global



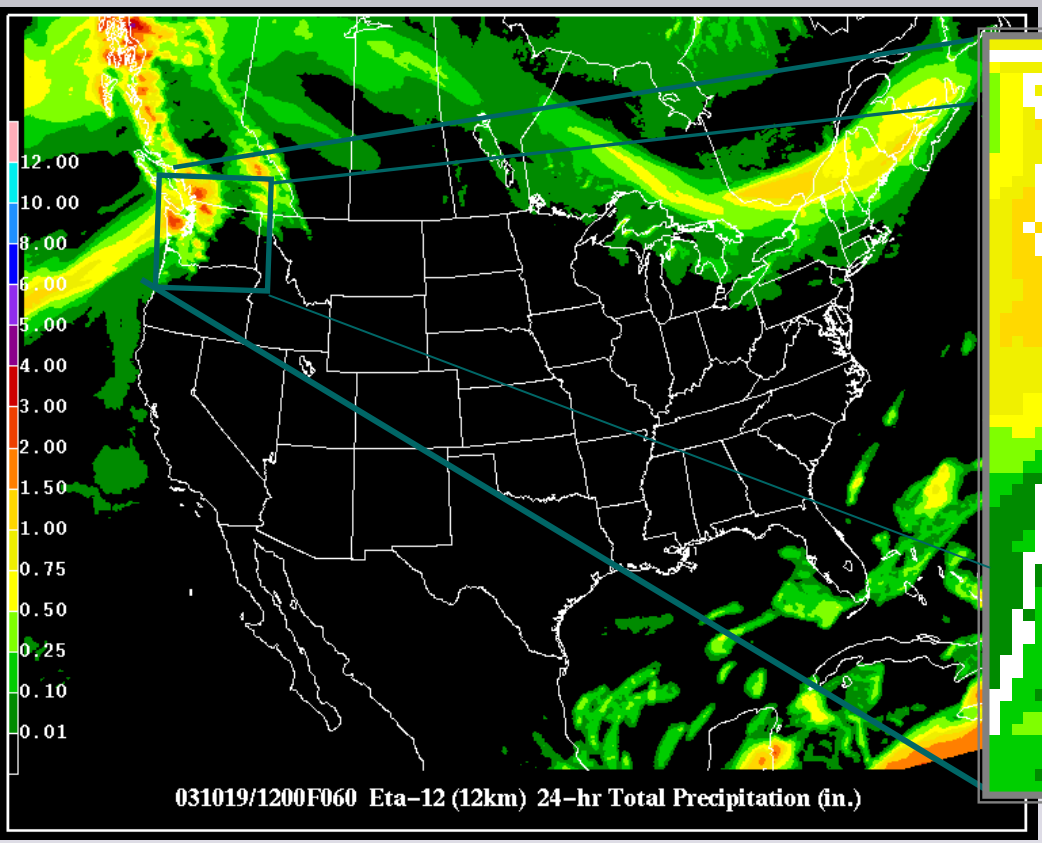


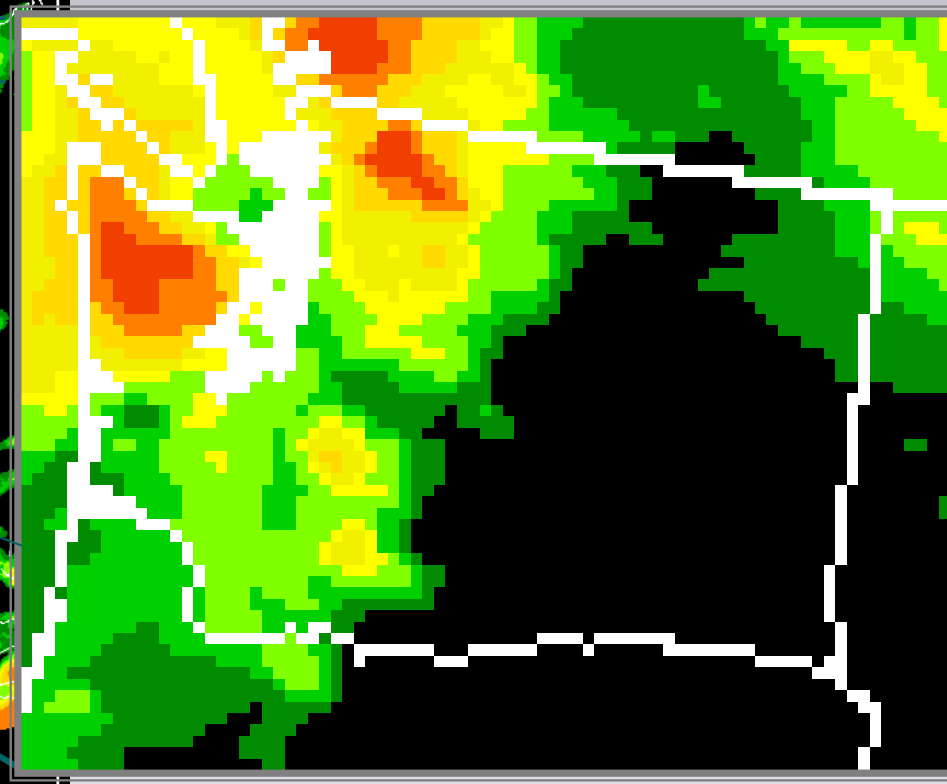
NRL 0.25° 6hr Microwave Global

Eta Model Forecasts

- 12,20, and 40-km grid, 0600 UTC (0000 MDT) run, 3-hr forecasts out to 48 hours
- Use the following Eta model parameters for calculating reference ET:
  - temperature
  - relative humidity
  - solar radiation
  - wind speed
- If weather station observations are not available, the previous day's 0600 UTC Eta model forecasts out to 24-hours are used to calculate reference ET

Eta 12-km Forcing – 1 km LSM Domain



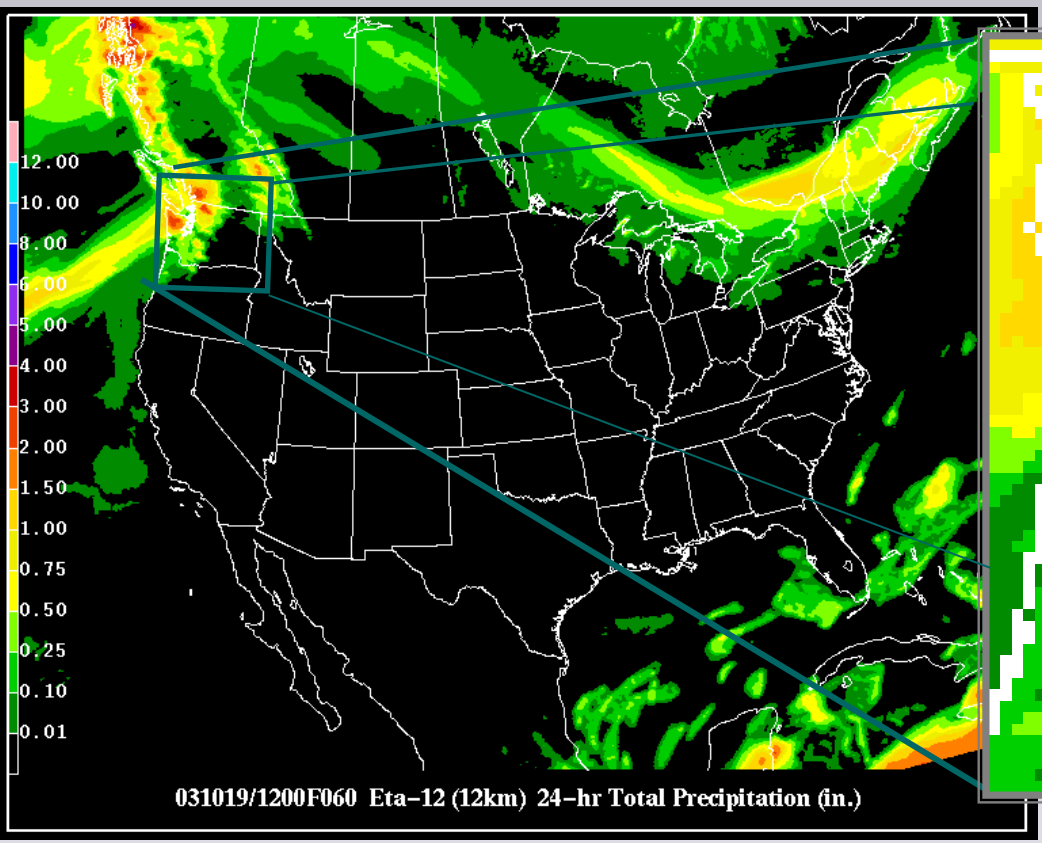


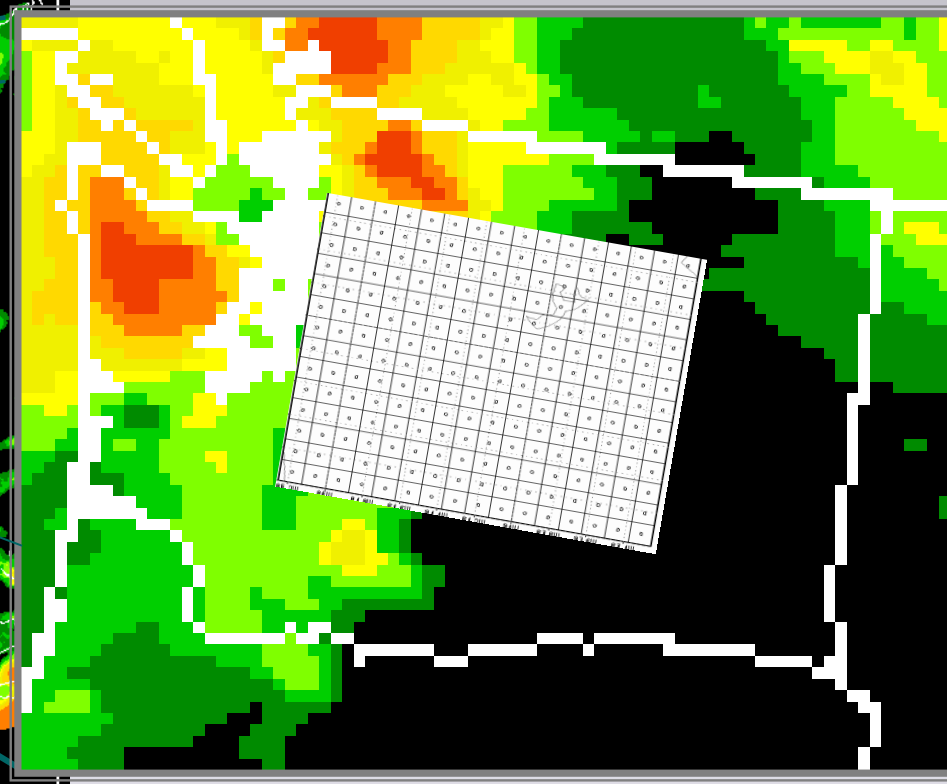
Plotted by Brett McDonald

1-km LSM domain could be set up to include certain MODIS datasets (e.g., land surface temperature) and other high-resolution remote sensing products. (Eta 12 km 12Z 60 hr forecast)

Continued

Eta 12-km Forcing – 1 km LSM Domain



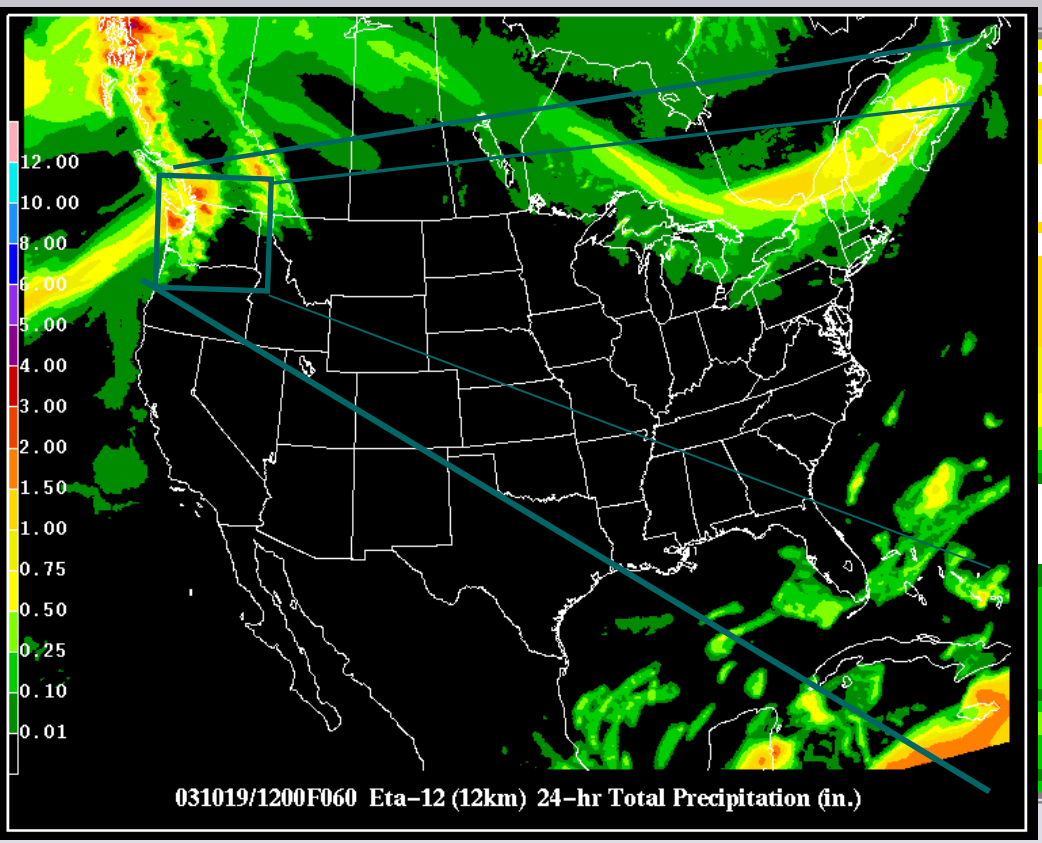


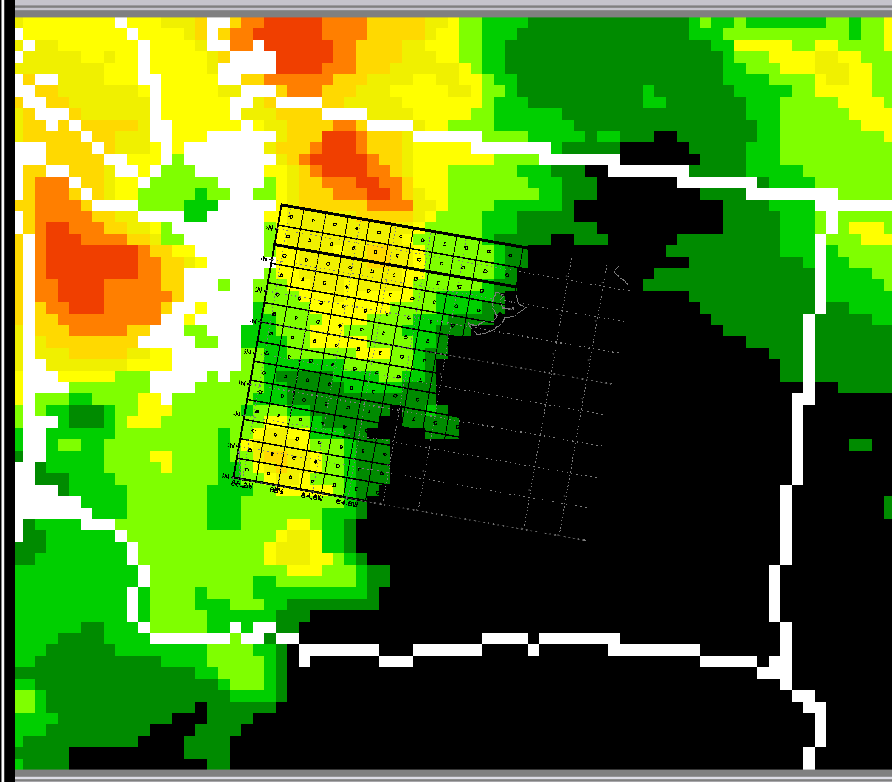
Plotted by Brett McDonald

1-km LSM domain could be set up to include certain MODIS datasets (e.g., land surface temperature) and other high-resolution remote sensing products. (Eta 12 km 12Z 60 hr forecast)

Continued

Eta 12-km Forcing – 1 km LSM Domain

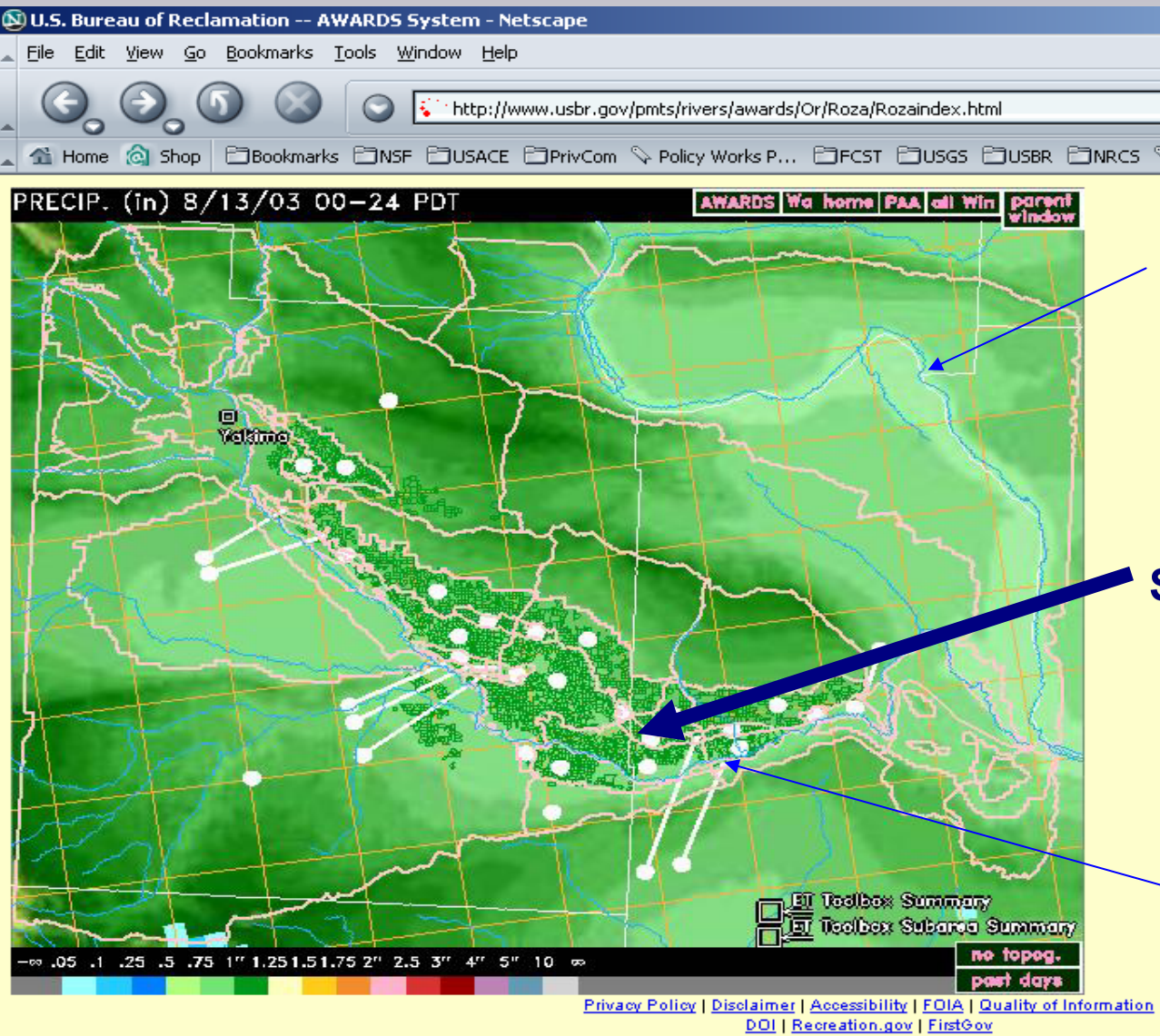




Plotted by Brett McDonald

1-km LSM domain could be set up to include certain MODIS datasets (e.g., land surface temperature) and other high-resolution remote sensing products. (Eta 12 km 12Z 60 hr forecast)

Zoom into Irrigation Canals


U.S. Bureau of Reclamation -- AWARDS System - Netscape
File Edit View Go Bookmarks Tools Window Help
http://www.usbr.gov/pmts/rivers/awards/Or/Roza/Rozaindex.html
Home Shop Bookmarks NSF USACE PrivCom Policy Works P... FCST USGS USBR NRCS SmartUpdate
PRECIP. (in) 8/13/03 00-24 PDT
AWARDS Wa home PAA all Win parent window
Yakima
ET Toolbox Summary
ET Toolbox Subarea Summary
-∞ .05 .1 .25 .5 .75 1" 1.25 1.5 1.75 2" 2.5 3" 4" 5" 10 ∞
no topog.
past days
Privacy Policy | Disclaimer | Accessibility | FOIA | Quality of Information
DOI | Recreation.gov | FirstGov

Columbia River

Sunnyside Canal

Yakima River

Comparison of Eta Model Forecasts with Surface Weather Station Data

Eta model grid cell 107.175 (2569 ft) & Ellensburg 8SE, WA (1856 ft)
160 Day Sample Period: June 12 - November 30, 2001 (12 days missing)

	Max T (F)	Min T (F)	RH (%)	Rain (in)	Solar (L)	WS (mph)	Ref ET (in)
Eta ave or total	66.55	47.61	53.57	4.90	480.08	5.76	0.181
Wxs ave or total	69.89	45.25	64.02	2.31	432.92	4.53	0.185
Wxs - Eta diff	-3.34	2.36	-10.45	2.59	47.16	1.23	-0.004
Difference in %	-4.77%	5.22%	-16.32%	112.12%	10.89%	27.12%	-2.03%
Correlation r =	0.975	0.935	0.901	0.205	0.949	0.657	0.968

- The large positive precipitation and surface solar insolation biases were expected - the approximate +11% solar bias agrees with Mitchell, et al., 2000 (see reference in preprint)
- There was excellent agreement in computed reference ET

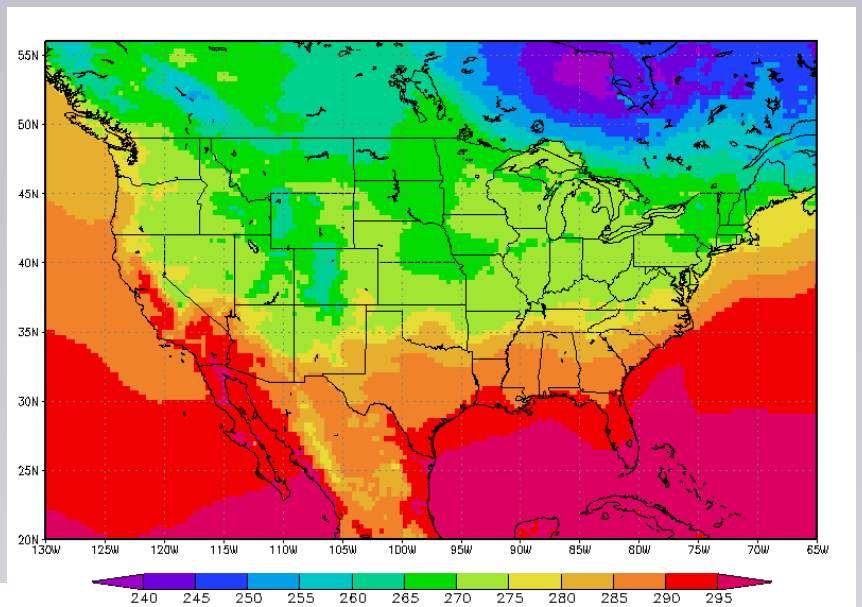
NCEP North American Regional Reanalysis

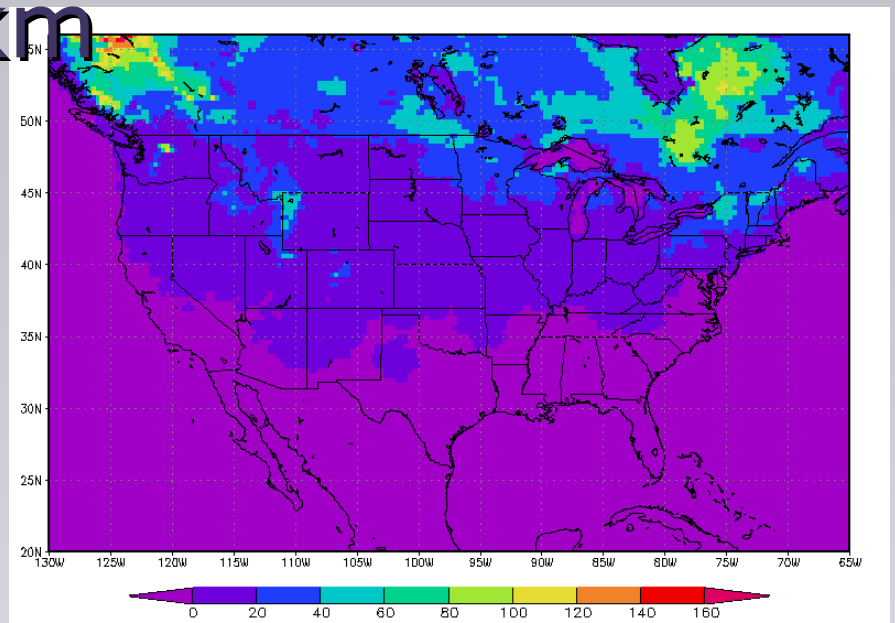
NCEP RR: Long-term analysis dataset over all of North America

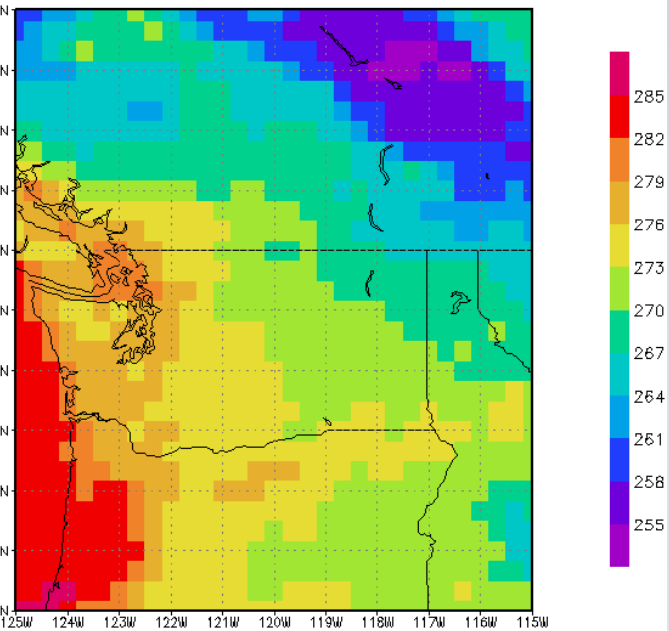
- 25-year, 1/3 degree dataset to provide longer term dataset (through present time)
- Being evaluated for use as the 1996 case study for Columbia/Yakima area
- Could be used for statistics and running the LSMs/watershed models

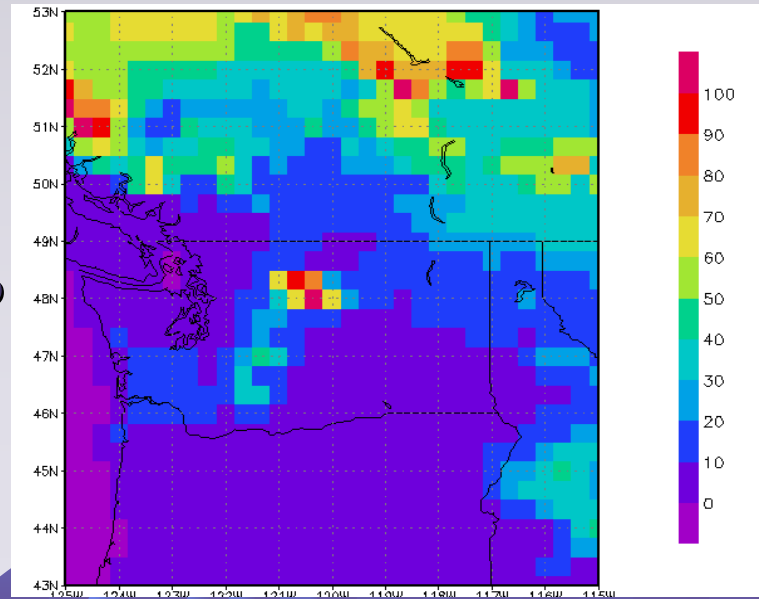
Duration: Oct. 1978 to Dec. 2003
Output Interval: 3 hr
Average File Size: 5.7 to 6.0 Mb
Total Years: 25.25 years

NCEP Regional Reanalysis = ~ 33 km

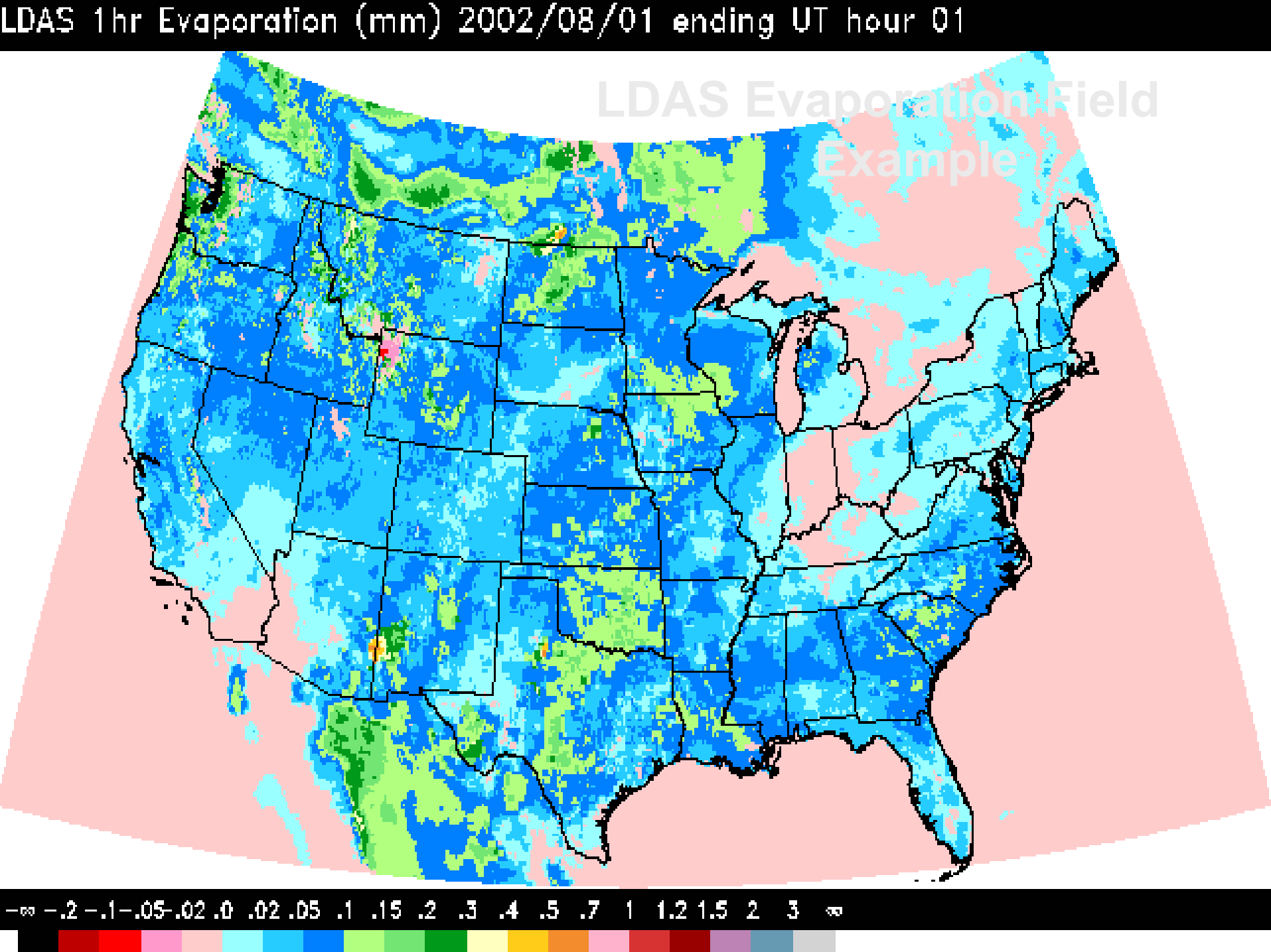






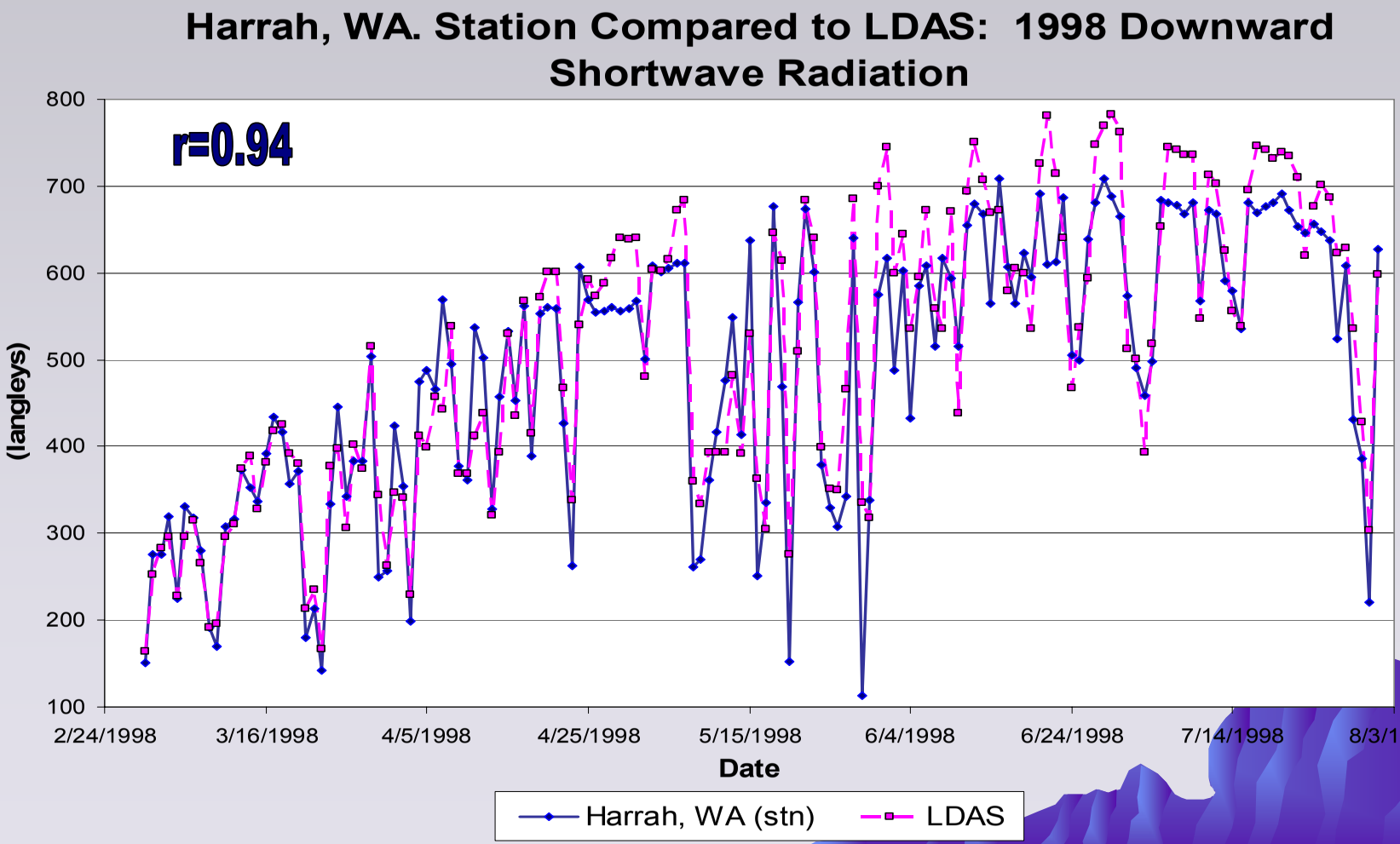


2m air temperature (top) and snow depth (bottom) for Jan. 1, 1996 (00Z)


LDAS 1hr Evaporation (mm) 2002/08/01 ending UT hour 01
LDAS Evaporation Field
Example 1
-∞ -.2 -.1 -.05 -.02 .0 .02 .05 .1 .15 .2 .3 .4 .5 .7 1 1.2 1.5 2 3 ∞

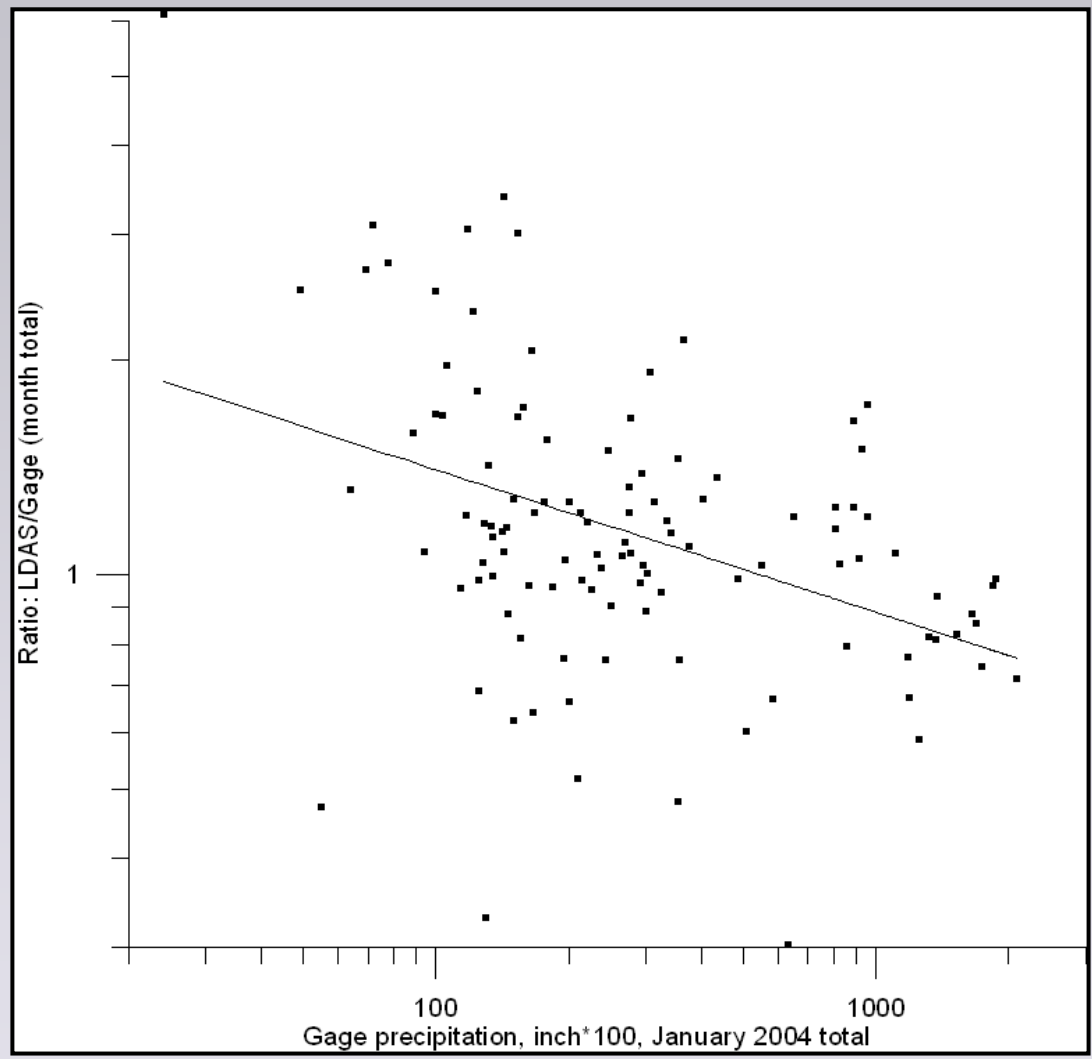
Forcing Validation

Validating the forcing datasets used in LDAS with Reclamation and other meteorological in-situ measurments in the Columbia River Basin area in Washington



LDAS Rainfall versus Gage

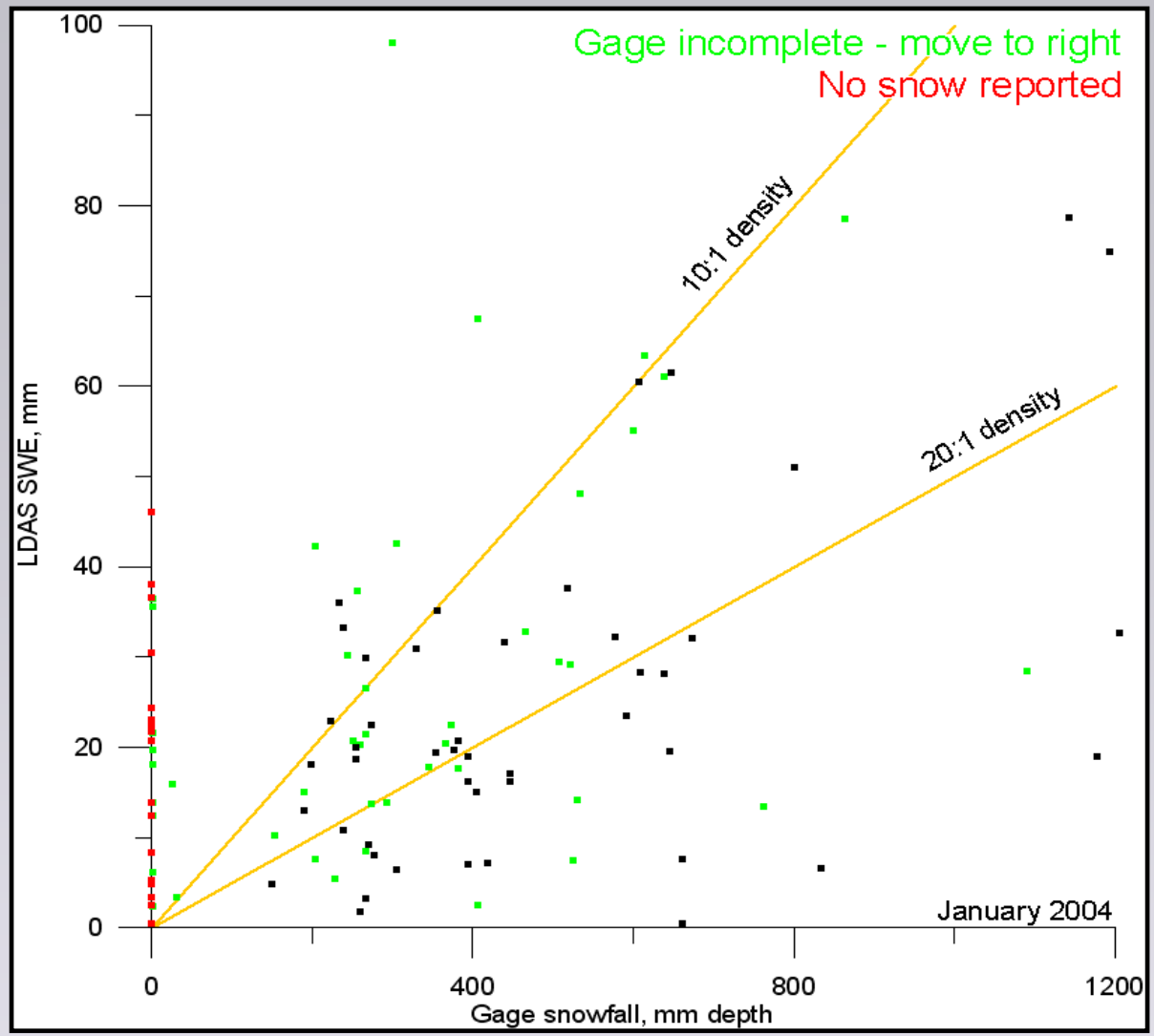
A ratio of LDAS sums for the entire month of January 2004, combining both "rain" and "snow" to make a total precipitation value



LDAS Precipitation Validation

- For comparison: 112 Climatological Data gages used
- Monthly totals
- The average ratio (logarithmic) converts to a linear ratio of 1.144, indicating that your LDAS is only 14 percent overestimating the precipitation.
- The scatter is mostly within a factor of 2 of truth
- The R-squared value to the fitted line is 0.1647; typical of radar data
- LDAS overestimates light precipitation and underestimates heavy precipitation.

LDAS Snowfall Versus Gages



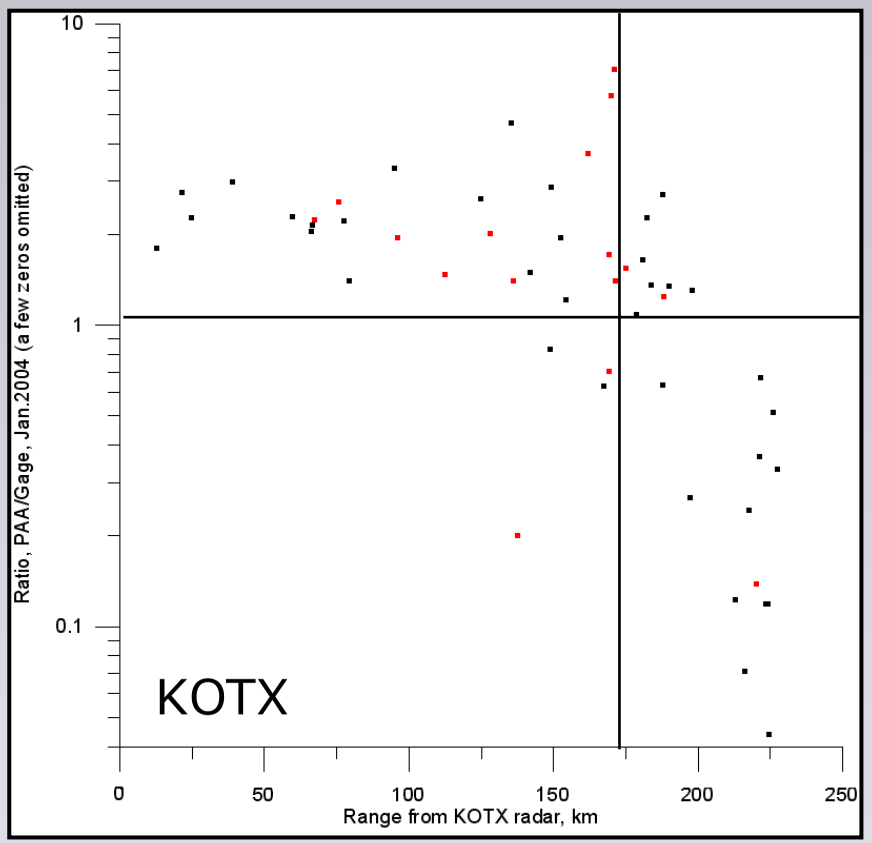
In general, the red points and nearby green points are where LDAS indicates snow, but nothing reached the ground.
Points significantly to the right of the 20:1 line indicate that LDAS has missed much of the snow that actually fell.

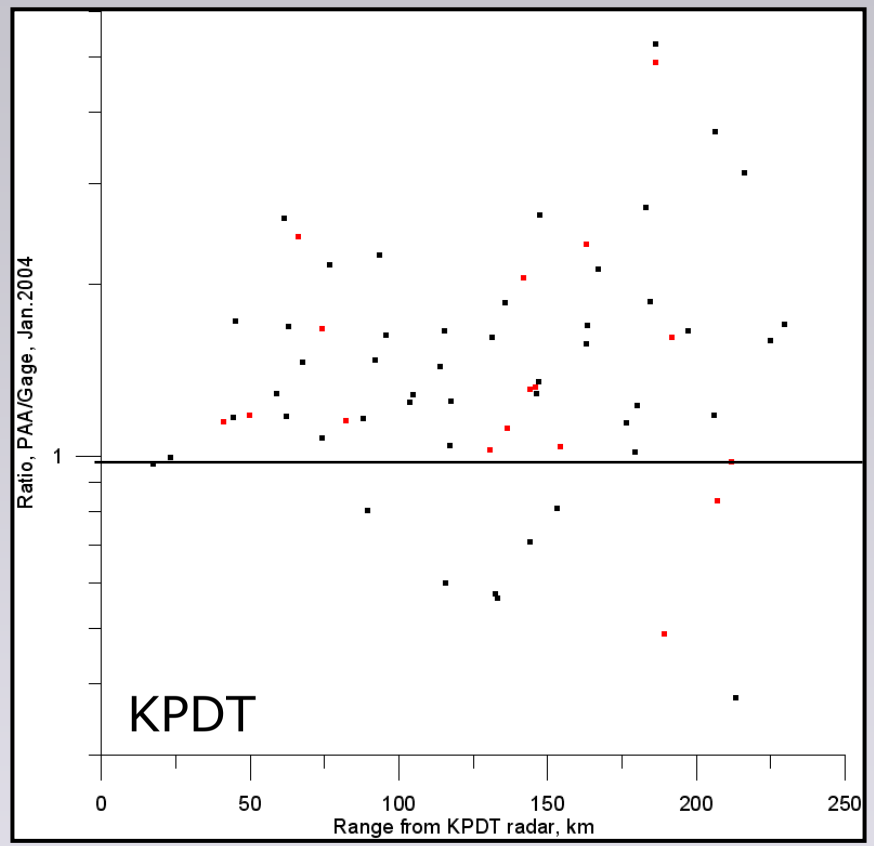
LDAS Snowfall versus Gage

- Monthly summary for all of January.
- Use the Climatological Data snow reports, summing the snowfall values and converted tenths of an inch
- The green points had at least one day with an indication of a missing value.
- The red points indicate that LDAS is indicating snowfall when the surface stations see nothing but rain.
- The black points indicate that the observations appear to be complete.
- Two yellow-orange lines:
  - One representing a 10:1 snow density (a standard value)
  - 20:1 snow density (fluffy).
  - The PAA uses an emperical value of 14:1.
- Points to the right of the 20:1 line generally indicate that the surface is seeing snowfall but LDAS is missing much of it.

Reclamation's PAA Versus Gage

ratios of PAA divided by Climatological Data gage readings





total precipitation for the month of January 2004

The red dots are for gages that missed a day or more and so their month totals are smaller than they should be; therefore the ratios are too big and should be made smaller by some unknown amount. All radars were operated on the same adaptable parameters converting dBz to precipitation rate

Doppler Radar Stations for PN Region

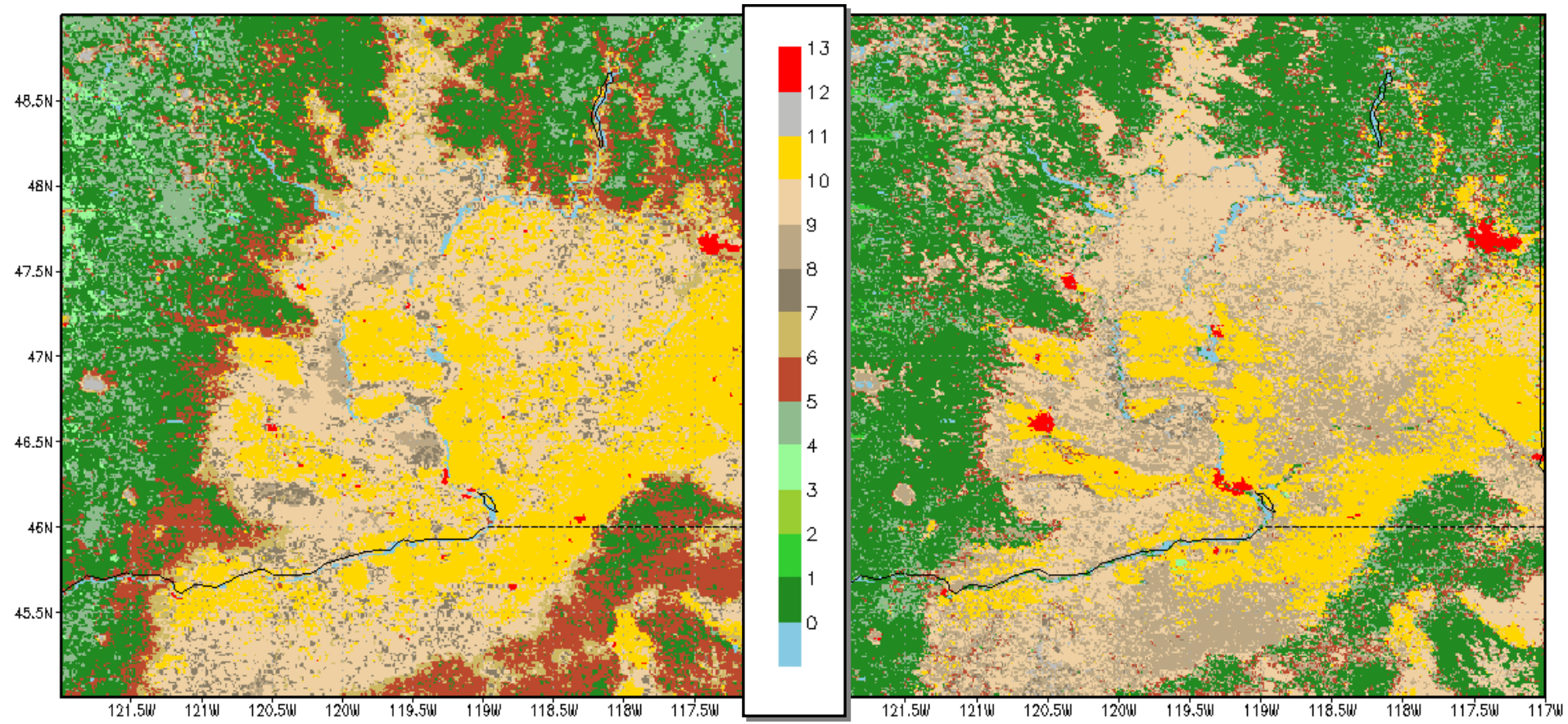
- KPDT (Pendleton) did not show much of the drop off with range. There is about a 50 percent offset to the points relative to 1.0, but the scatter about it is mostly within a factor of 2. The two gages at the radar were too close for radar comparisons.
- KOTX (Spokane) has a greater offset, being more than twice the gage values but starts to have the range drop off after 150 km. There were only a few gages at which the radar saw zero echo.
- KATX (Seattle) has severe blockages by the Cascades as it looks into the study area from the west side. The ratios start to get small at about 120 km range and drop rapidly after 150 km. There were many gages for which the radar saw zero echo because of blockages and tilt overshoots. The logarithmic scale automatically excludes them. For short ranges the scatter is close to 1.0. .

- All radars interacted with the bright band, but the PAA software tries to deal with that using some general emperical values and consideration of the fraction of the beam involved with bright band. Another, and most likely, problem is with virga. The coastal radars are seeing mostly precipitating cloud, and so the ratios are close to 1.0. After the air passes the Cascades there is a decrease in precipitation reaching the ground with inland distance. The radar beam still sees echo aloft. The revised PAA tries to use the humidity of the surface air to help reduce virga, but it appears that some fine tuning is needed; the adaptable paramter was derived in Arizona.

Project Areas

Land Surface Model Comparison

- LIS LSM Simulations for Evaluation:
  - NCAR Community Land Model (v2)
  - Noah LSM (v.2.6 and v.2.7.1)
- Land Cover Datasets used
  - AVHRR – UMD Classification
  - MODIS (v004) – EDC/Boston U. (UMD)
- 1km STATSGO Sand, clay, and silt %
- Satellite Leaf Area Index
  - AVHRR
  - MODIS



AVHRR

UMD Land Classification Dataset

MODIS (V4)

Obtained from EDC and Boston University

Snow pack Monitoring

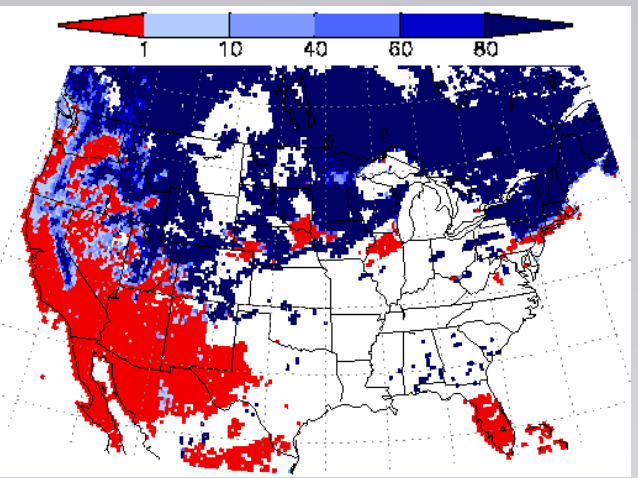
- Two main areas of improving snowpack estimates and forecasts:
  - Remote Sensing Products
    - MODIS Snow Cover, albedo, vegetation cover at 500 m
    - AMSR-e Snow Water Equivalent at 25 km
  - Land Surface and Snow Models
    - LSMs: Noah, CLM2, VIC
    - Snow Models:
  - Forcing Datasets:
    - QPE-SUMS, PAA, Eta-12 km, LDAS forcing products
    - North American Regional Reanalysis (~32 km, 25year)

LDAS Snow Updates Using MODIS Data

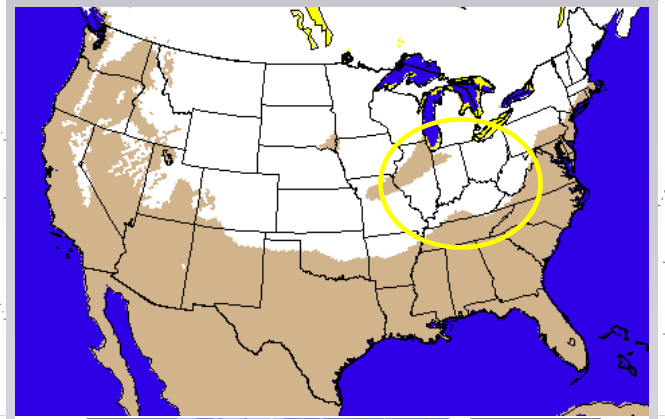
Matt Rodell
Hydrological Sciences Branch, NASA GSFC

21Z 6 February 2003

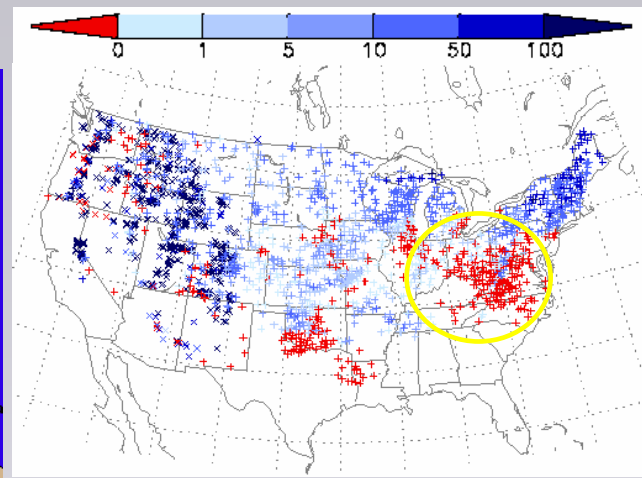
Enhanced MODIS Snow Cover (%)



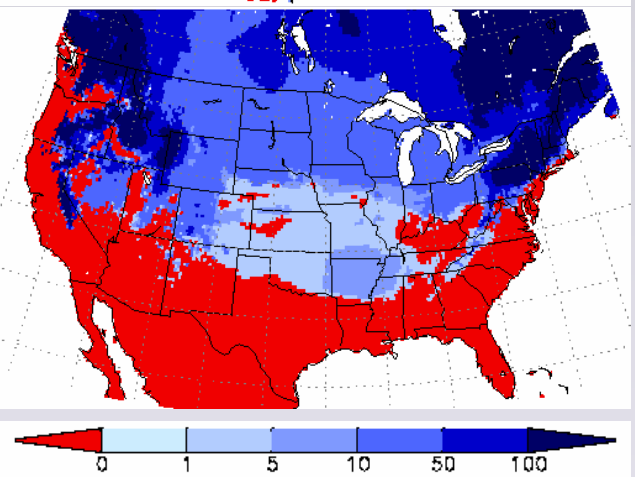
IMS Snow Cover



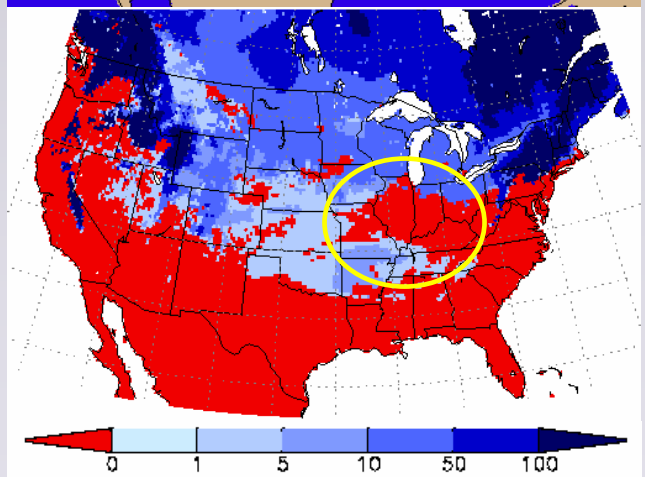
SNOTEL and Co-op Network SWE (mm)



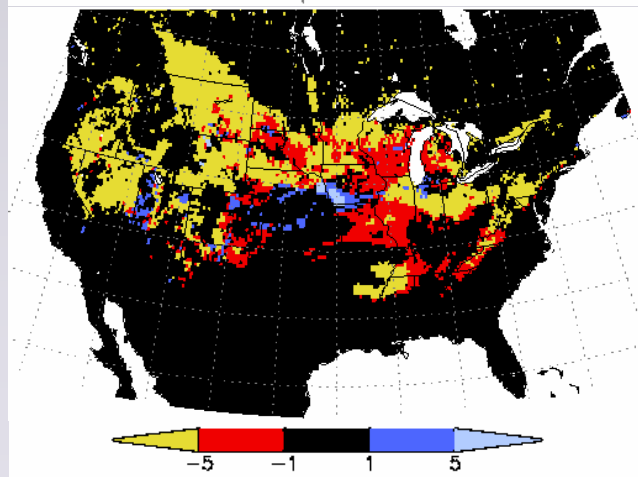
Control Run Mosaic SWE (mm)



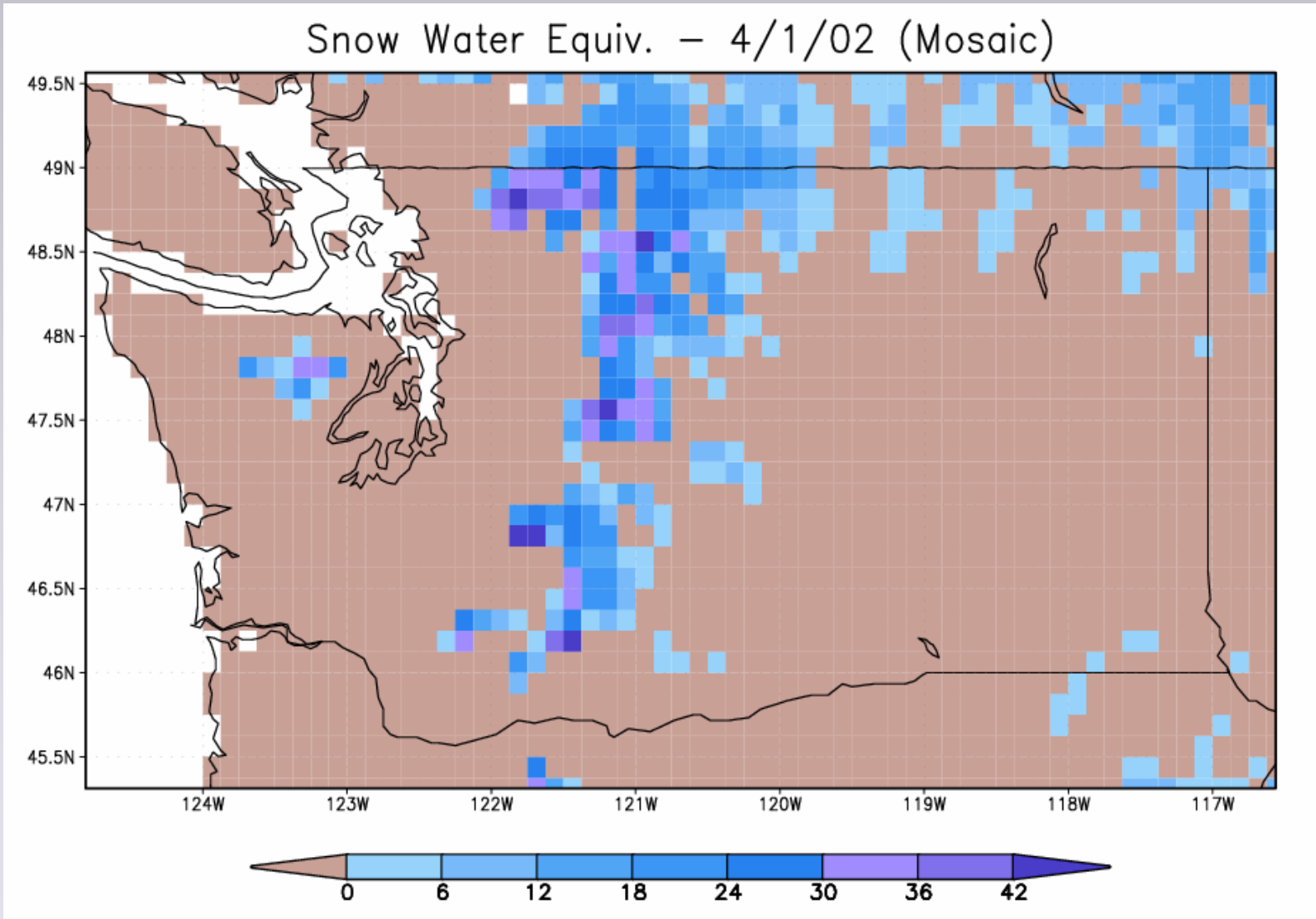
Assimilated Mosaic SWE (mm)



Mosaic SWE Difference (mm)



Example of Mosaic LSM Snow Water Equivalent (in.) of the snowpack in Washington as of 00Z on 04/01/2002.

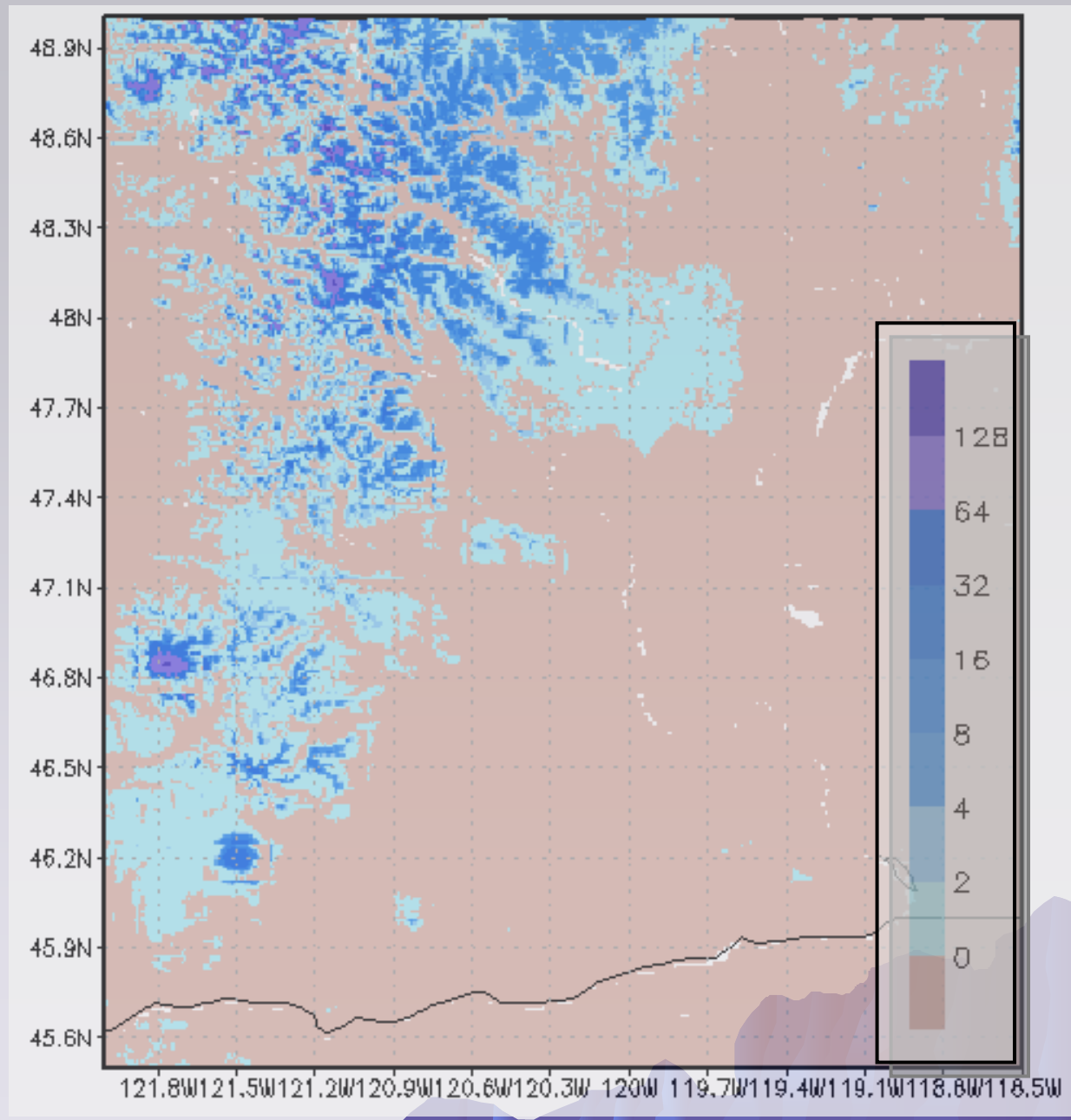


Yakima Basin, WA
1km SWE (mm)

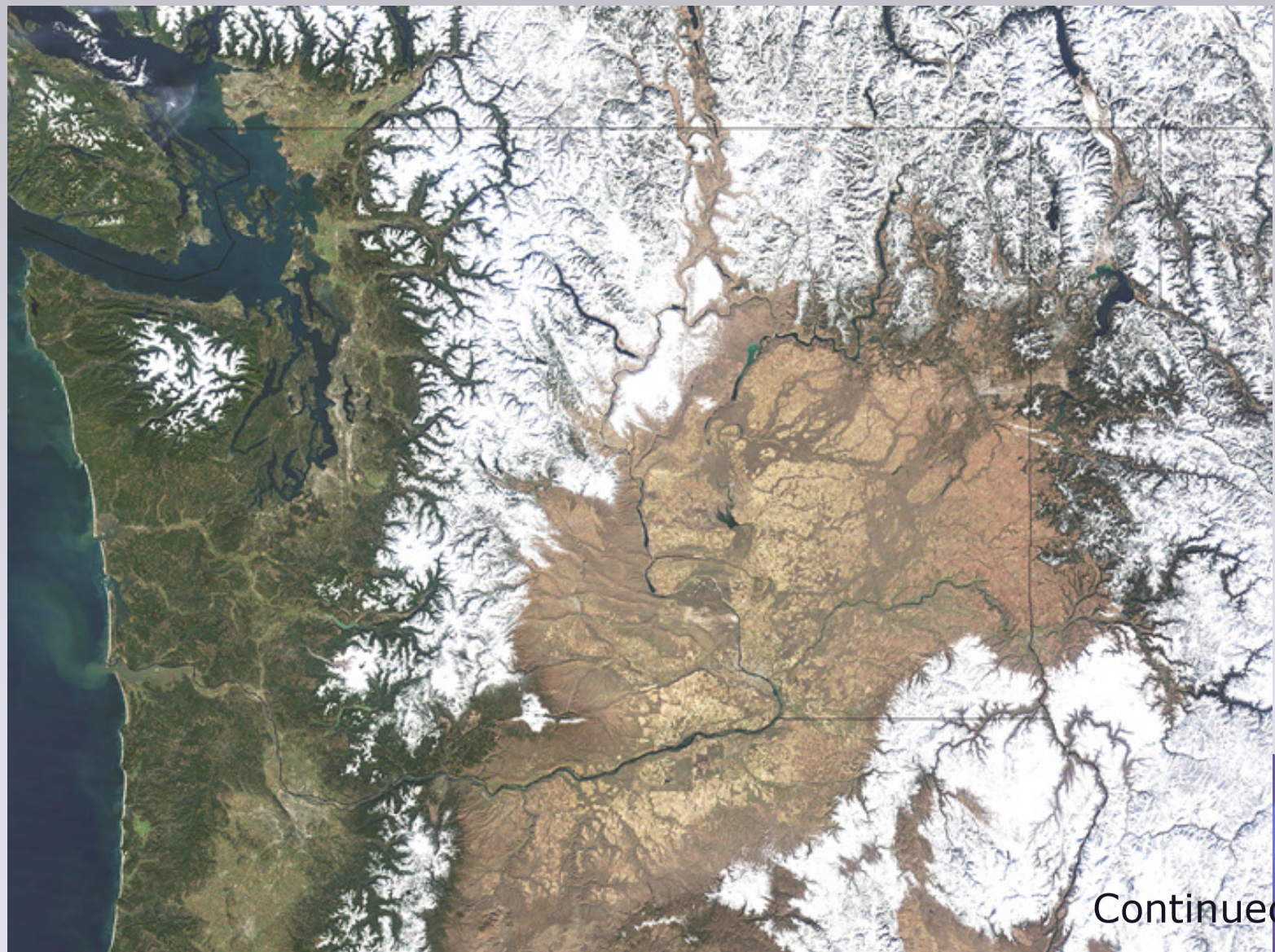
Nov. 11, 1999 (00Z)

SWE generated by the Noah LSM (v. 2.6) with:

- 1km elevation adjustment to forcing
- Statsgo 1 km soil percentages
- 1km MODIS vegetation type

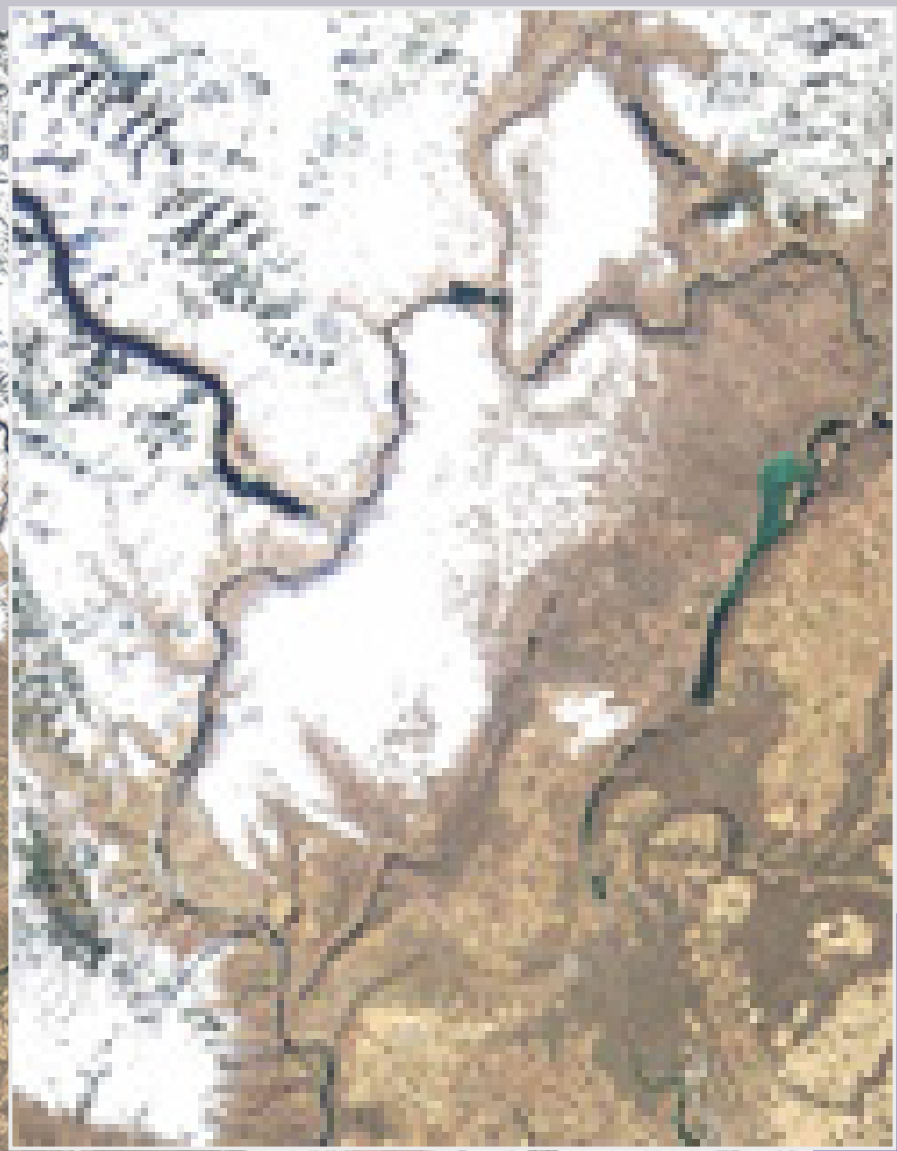


1-km MODIS Snow Cover



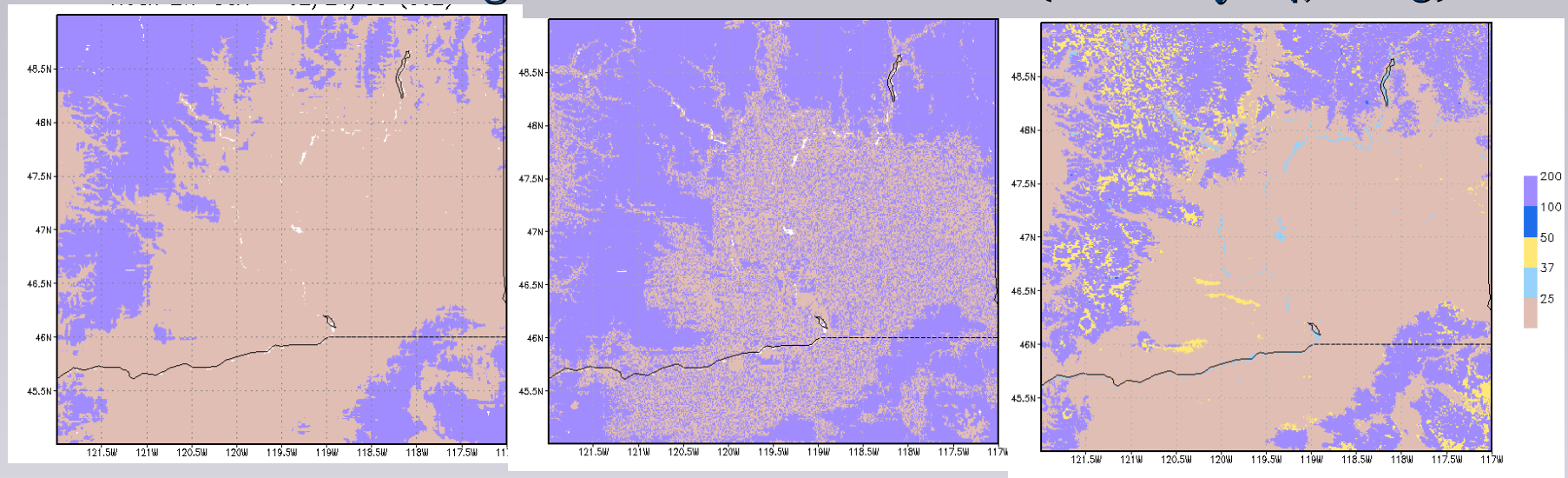
Continued

1-km MODIS Snow Cover



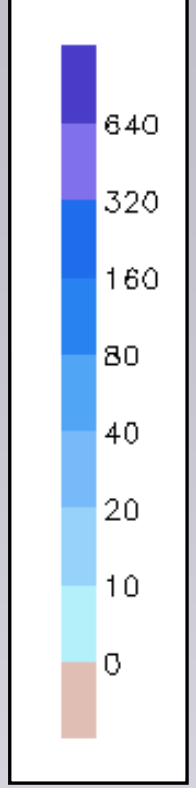
LDAS LSM and MODIS Snow Cover Comparison

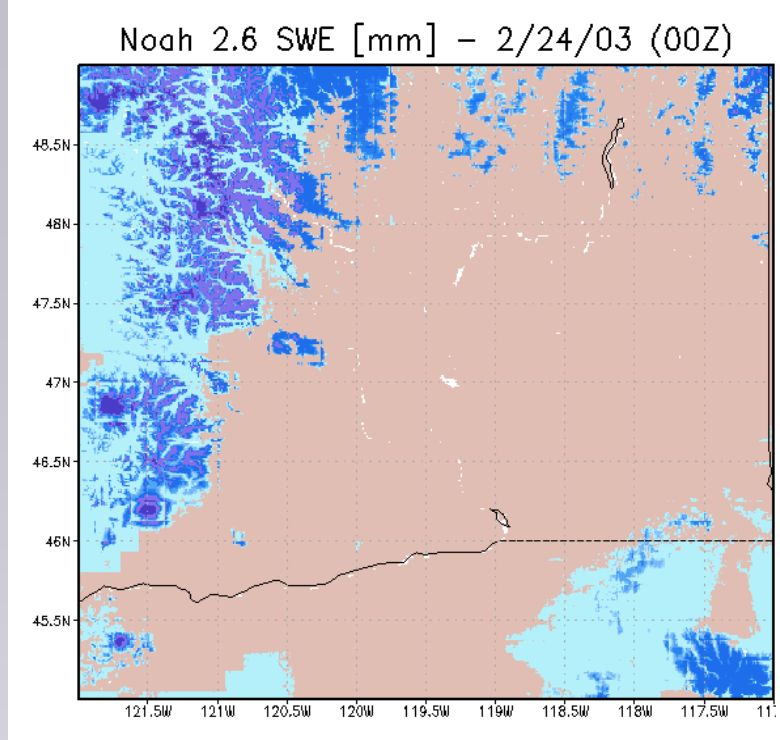
Central Washington State – Yakima Basin (February 24, 2003)

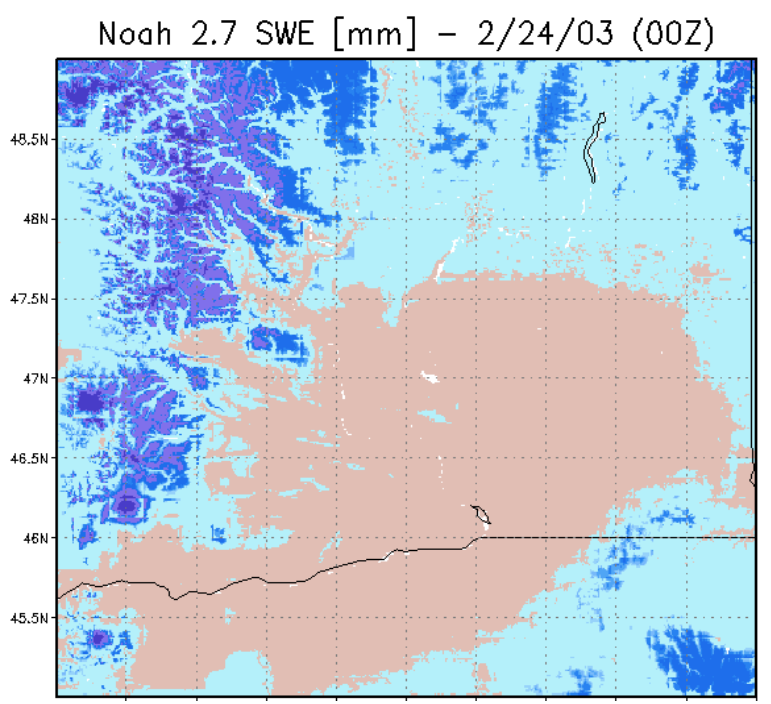


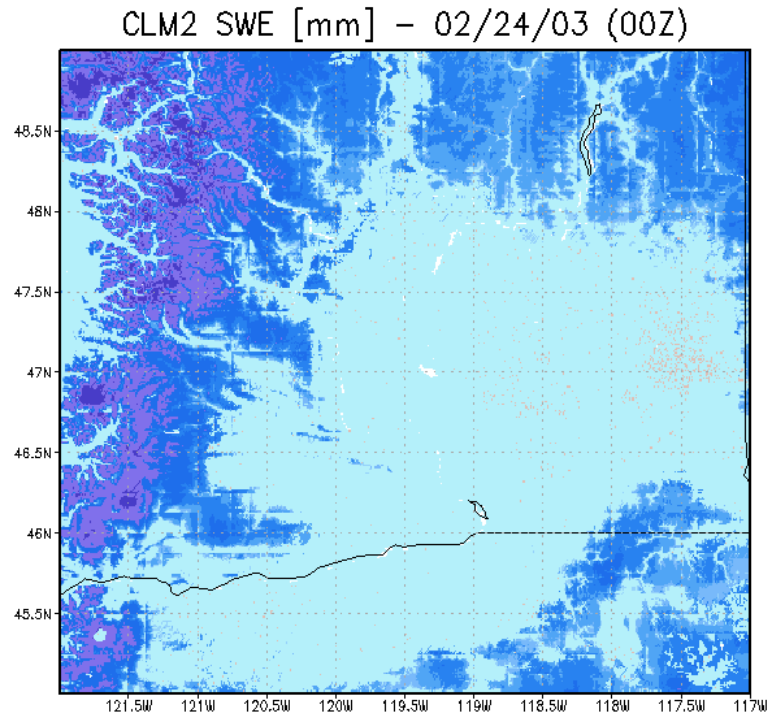
Noah 2.7.1 LSM **CLM2 LSM** **MODIS 1-Day**

- Comparison between the LDAS LSMs snow cover fields and Terra MODIS daily snow cover extent. (Purple indicates ***snow***, yellow is ***clouds***, and beige is ***snow-free land***.)
- Noah LSM underestimates and CLM2 overestimates snow cover when compared to the MODIS 1-day and also 8-day fields for most of the winter (for WY2002-2003).
- In later spring months when snow melt occurs, the model snow cover has been found to identify snow in locations that MODIS algorithms fail to locate the snow beneath the tree canopies, when compared to in-situ measurements.



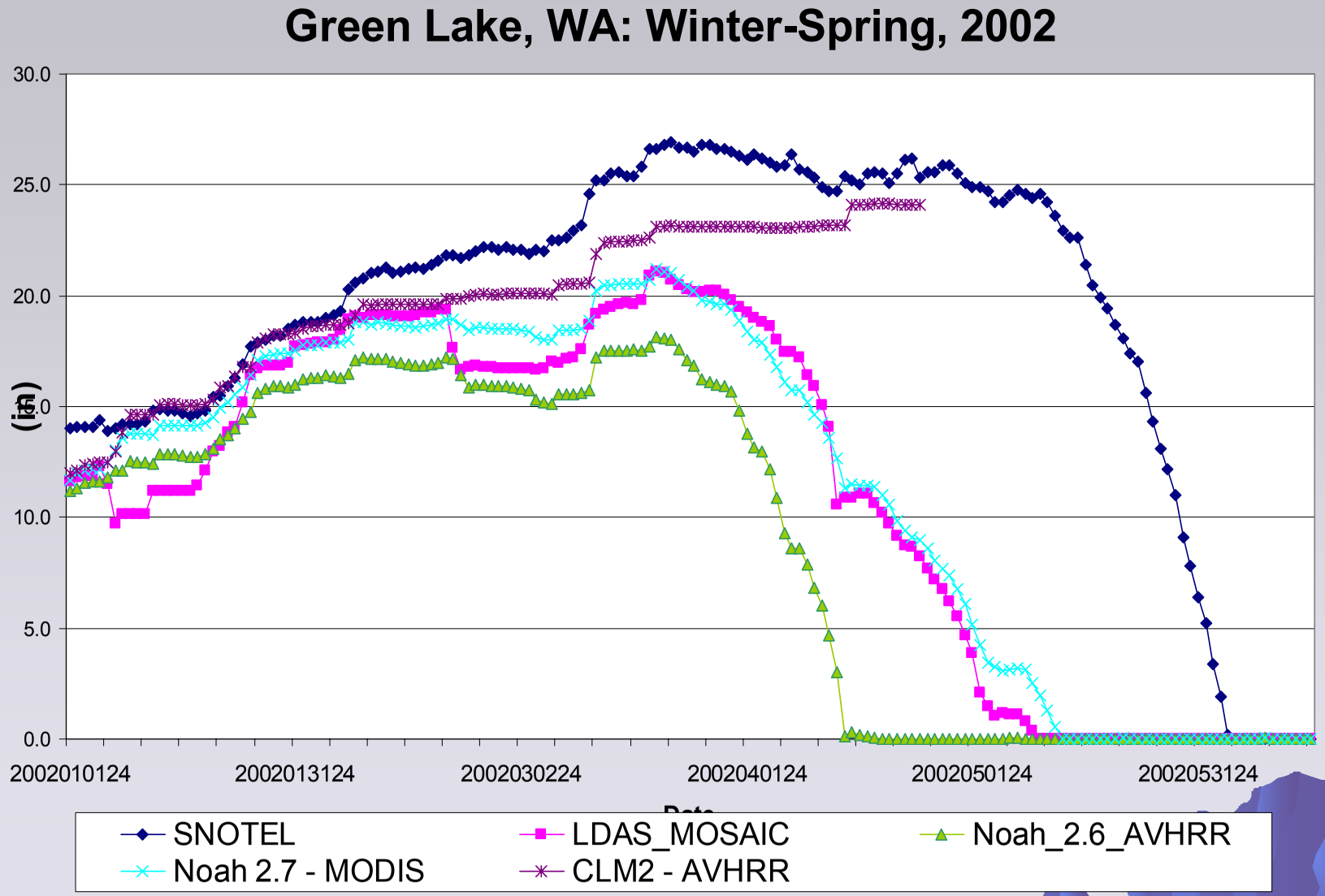






- Snow Water Equivalent (mm):
  - Noah 2.6
  - Noah 2.7.1
  - CLM2
    - * AVHRR Land Cover Used

SNOTEL versus LSM SWE: Example



Summary of Modeling Results

- When compared with SNOTEL snowpack measurements, the LSMs capture trends realistically, but tend to melt too much snow off and too early in the spring months.
- SWE is mainly underestimated in all the models at most stations, with an exception for CLM2 which tends to overestimate at certain stations
- Noah 2.6 and 2.7.1 significantly underestimate SWE, though 2.7.1 is much improved over the previous version

NWS Snow Data Assimilation System (SNODAS)

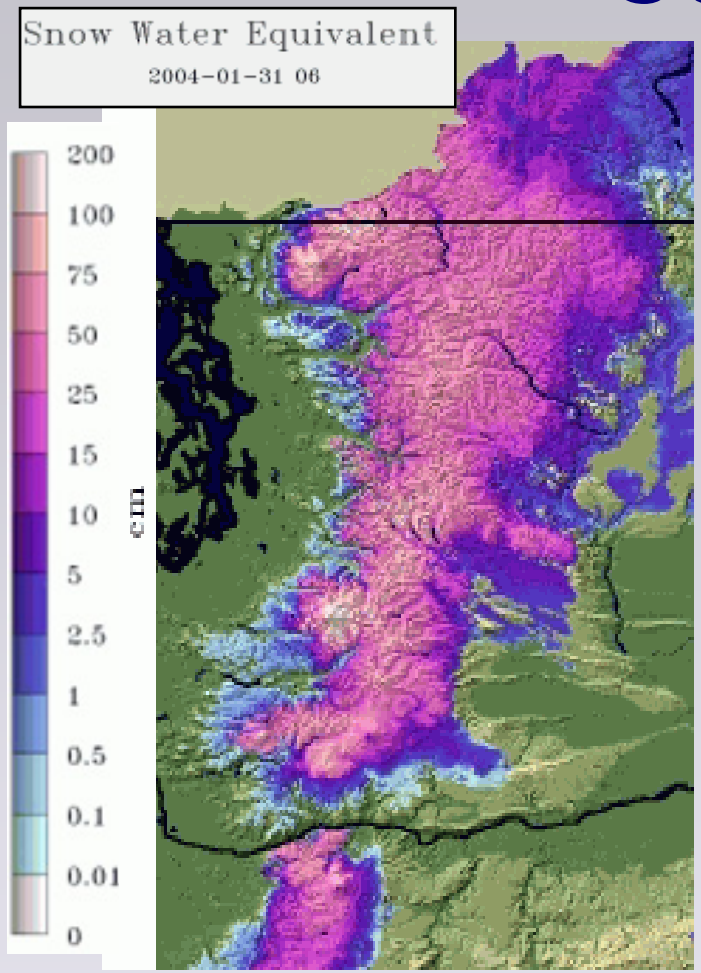
A spatially distributed snow energy and mass balance *model* is heart of system

Model forced by gridded solar radiation, air temperature, relative humidity and wind speed, physically scaled to 1 km resolution using multiple atmospheric layers and digital elevation model.

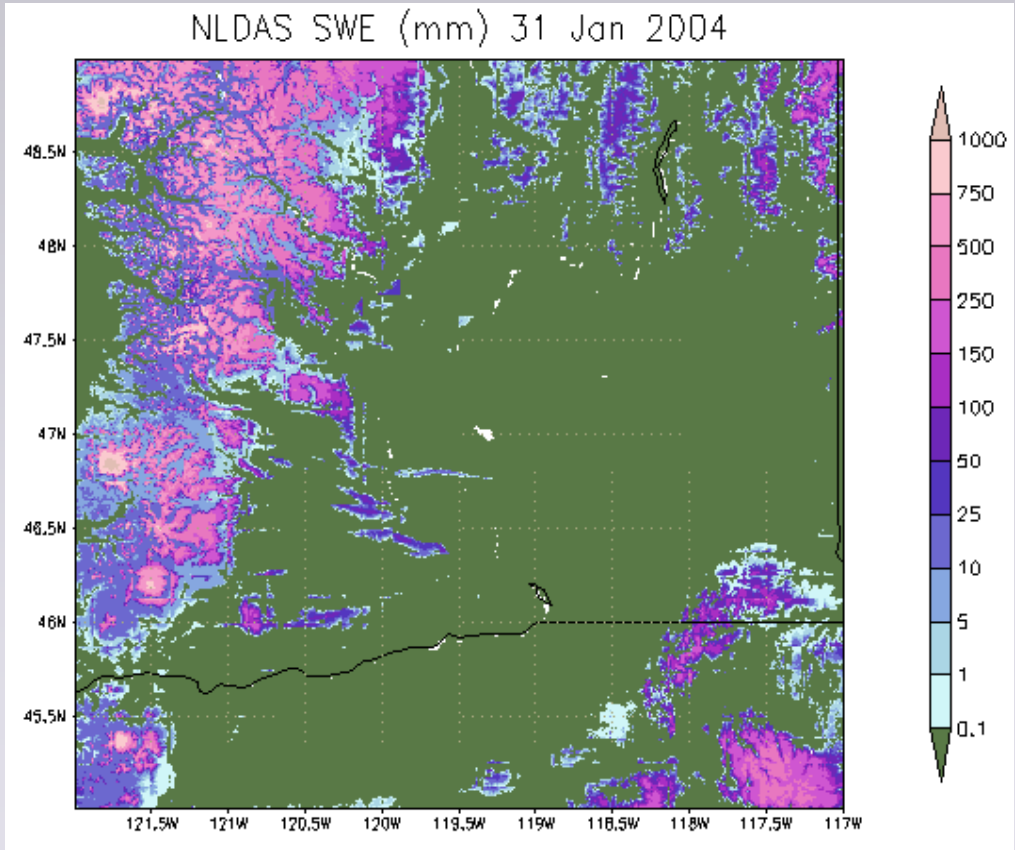
Model updated with all available SWE, snow depth, and snow cover (from surface, aircraft, radar, satellite)

Model outputs include SWE, Snow Depth, snowmelt, pack temperature, sublimation

Snow Water Equivalent (SWE) Comparisons



NWS Snow Data Assimilation System (SNODAS)



NLDAS (NOAH LSM)

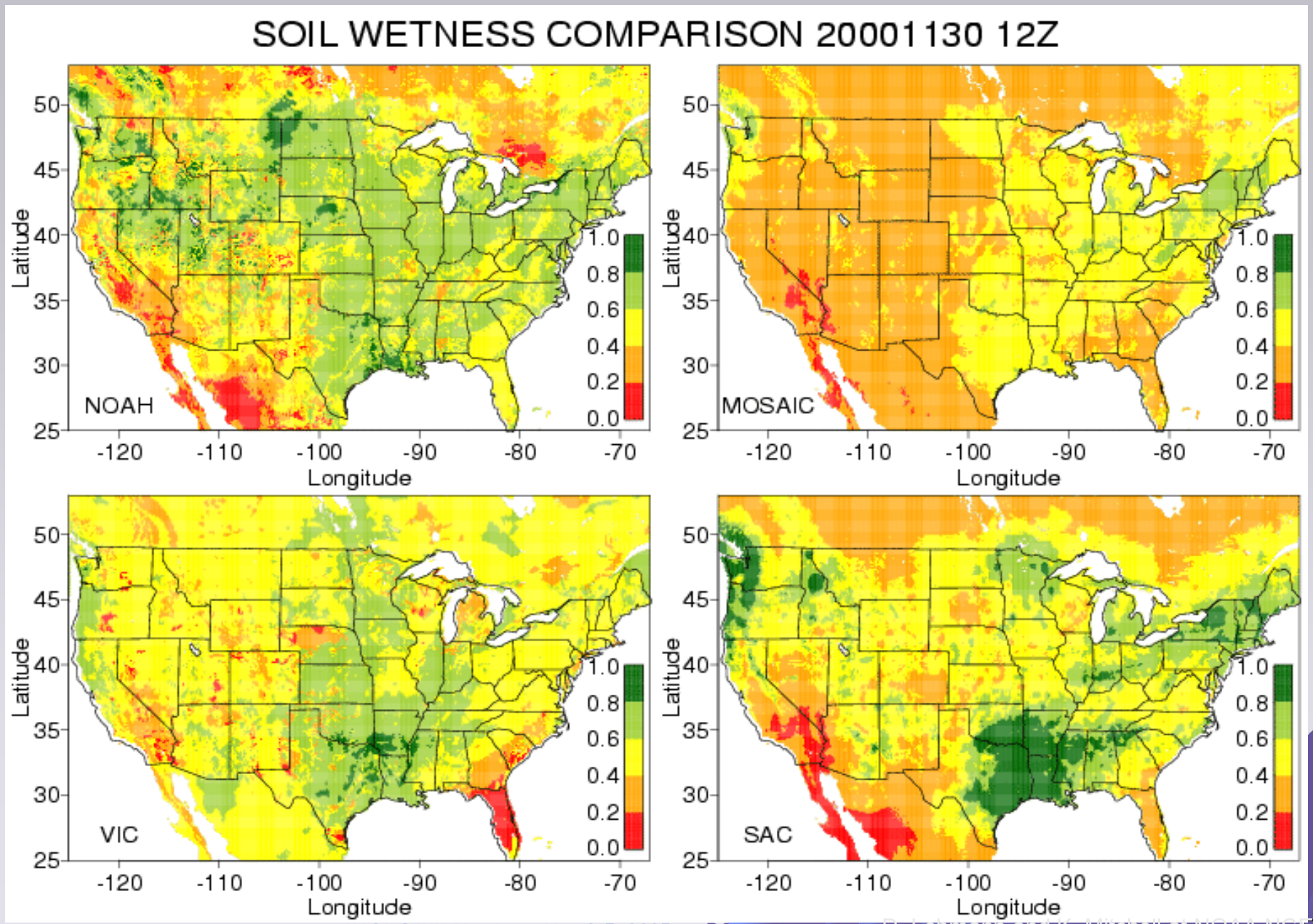
Data Acquisition and Analysis

- Reclamation acquires binary NLDAS data via anonymous FTP to NASA HSB server (large files)
- Using Grid Analysis and Display System (GRADS) to view and manipulate data
- Using GIS software to perform some verification/validation
  - TNT/MIPS and ArcGIS software

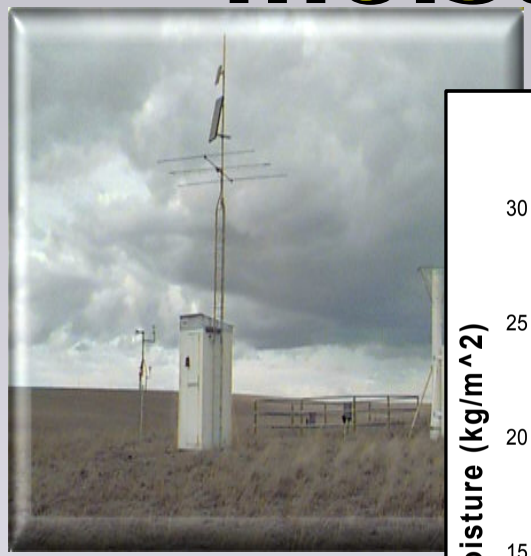
Soil Moisture

- To verify NLDAS
  - NRCS "enhanced" SNOTEL sites have direct soil moisture from buried dielectric constant probes
  - Units are water volume fraction - volume of water to volume of soil+air, in percent)
  - Installed (most locations) only before winter 2004-2005

LDAS Soil Wetness Comparison



Validation of NLDAS-Mosaic with SCAN in-situ soil moisture measurements

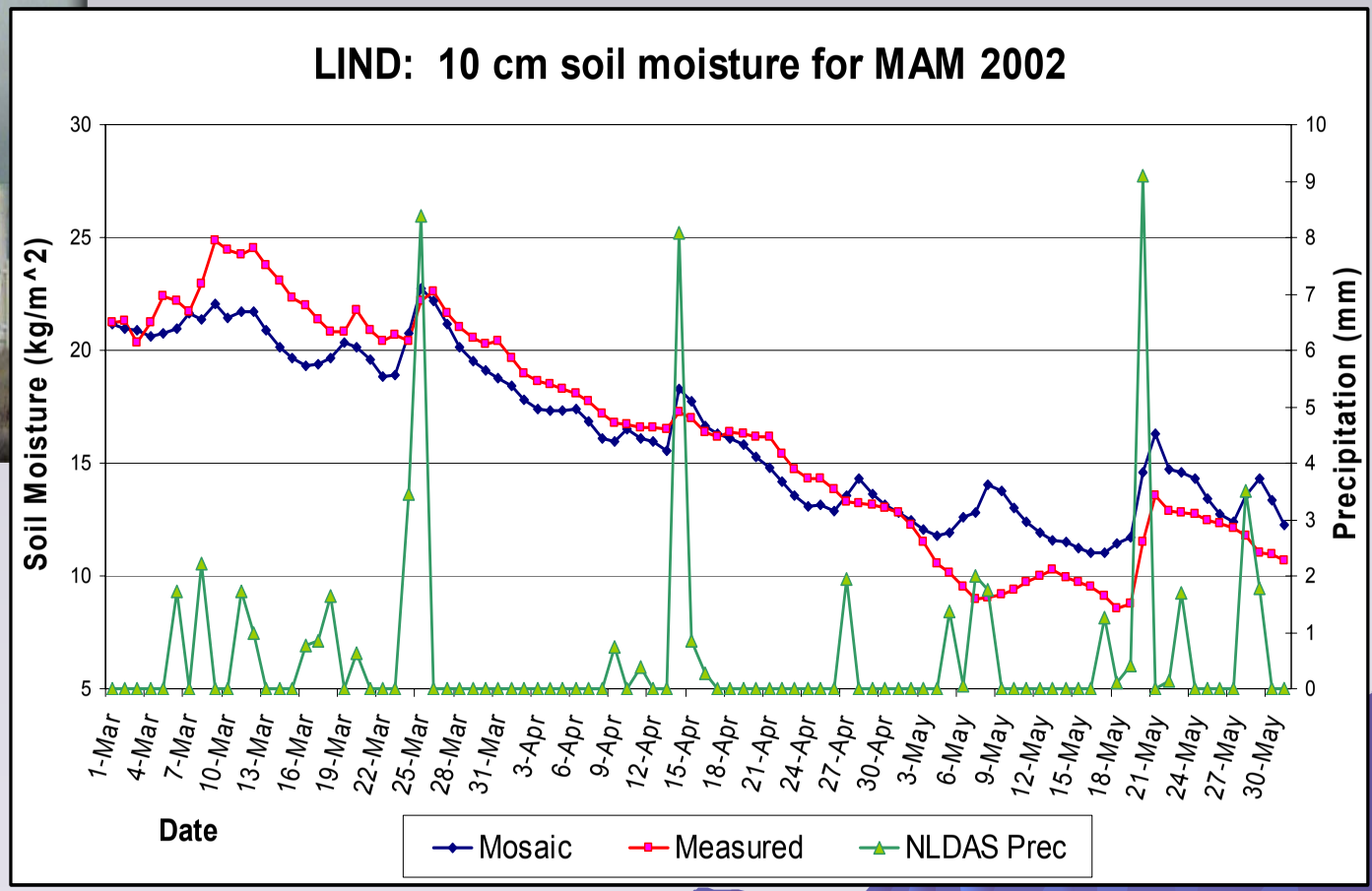


Lind, WA

Lon: 118.50° W

Lat: 47.00° N

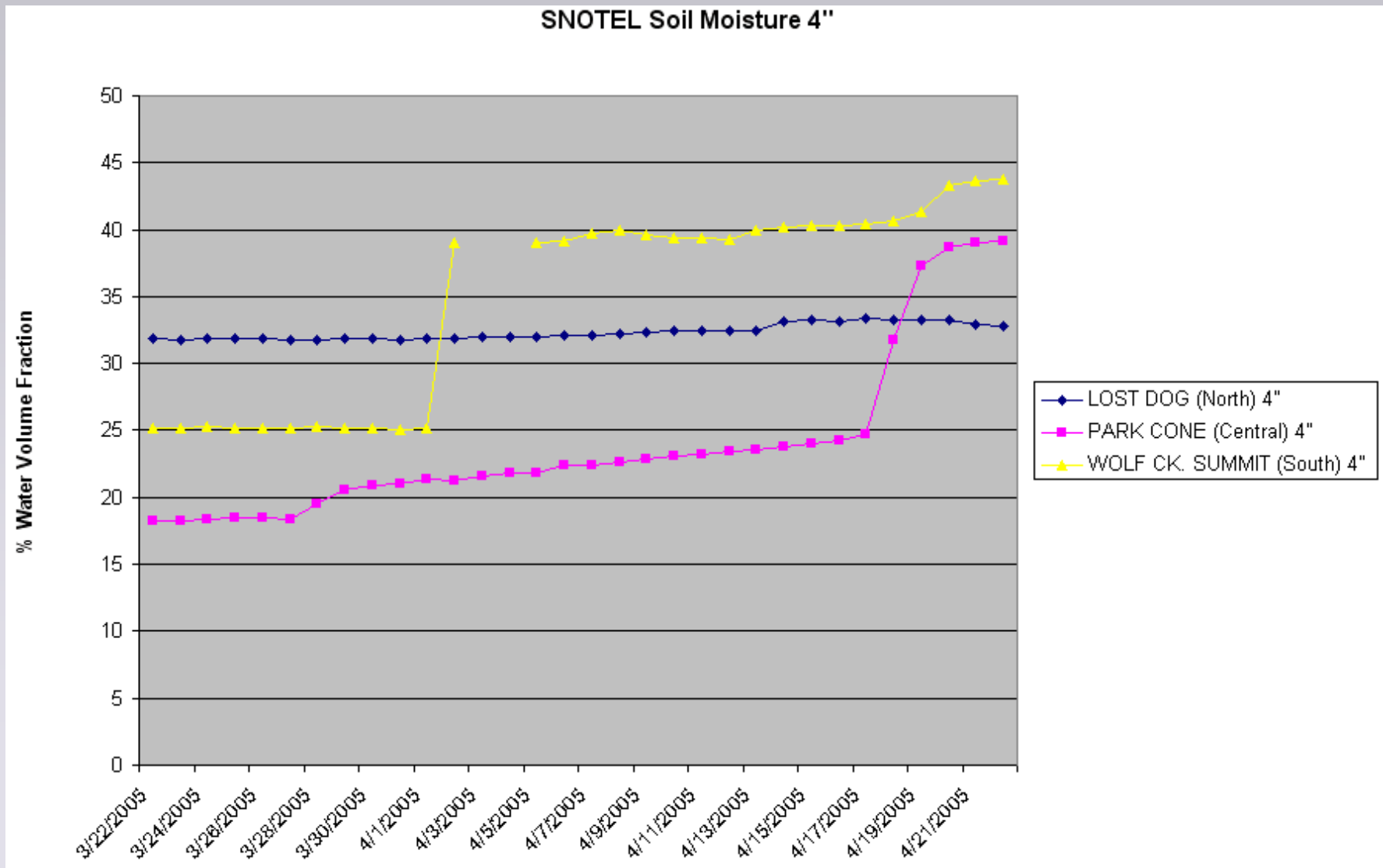
Elev: 500 m



SNOTEL Soil Moisture Measurements

- http://www.wcc.nrcs.usda.gov/snotel/Colorado/colorado.html
- Most of these sensors were installed sometime last summer, so the data record is pretty short.
- Soil saturation occurs at around 40% moisture volumes, during spring meltout. Of course, this varies by soil type and individual sites.
- Limited data record and need of further calibration
- In Utah, this data has been used for awhile now and estimate a soil moisture deficit in inches, to help them estimate how much SWE might be lost to soil recharge during the melt season.

Example of soil moisture measuremsnts at 3 spatially separate SNOTEL locations



Current Issues Being Addressed

- LIS is currently at 0.01 degree resolution (on geographic coordinate system) – 1/100 pixels per 1 degree gridbox . . .
  - In reprojecting the sinusoidal projections of MODIS V004 datasets, we face loss of geolocation information of original pixel position and change in shape of areas and nearest neighbor fill error
  - Found ArcGIS (8/9 vs.) and other tools like MODIS Reprojection Tool all create different map and shifts in pixel locations when used to reproject to current LIS domain and resolution

Issues being Addressed

- Working to do LSM vs. station measurement comparisons by running the models at the actual station location (with local forcing data and parameter information)
- Setup LIS for other projections and resolutions that better retain geolocation information (e.g., UTM)
- New software being developed for quality checks on the MODIS, ASTER, and GOES datsets being assimilated into the LSMs

Current Progress

- NASA-GEST researchers have set up an anonymous ftp server location for Reclamation to download in realtime and retrospective model simulations
- Reclamation is further validating the LIS/LDAS LSM output for use in their modeling tools and decision support systems
- Jointly analyzing MODIS, ASTER, and GOES datasets for use in LIS and scaling approaches to correctly represent these datasets in the models and DSTs

Summary

- NASA/UMBC/Reclamation researchers are working to apply NASA remotely sensed and modeling data to Reclamation's DSSs
- To improve the information and increase the amount of data on water availability to water resources managers and researchers to make more informed decision making for water resources issues faced in the West